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LEVEL II

Engineering Analyses of Candidate Communication and Surveillance Techniques for the Vessel Traffic System

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16. Abstract

Coast Guard Vessel Traffic Service (VTS) facilities rely heavily on radio communications to acquire the location of vessels and disseminate this information to other interested shipping. As the communication requirements change, the Coast Guard must be knowledgeable of the options available to meet the new requirements. To provide a basis for future system expansion and design, this study explores the communication channels available to maritime mobile service and the impact of change from voice to voice/data and data-only communication. ~~The~~ analyses performed under this study were divided into two tasks. Task I is ~~a~~ review ~~of~~ all frequency bands available for maritime service, identifying for each band all permissable transmission methods. Task II considers three candidate systems. The performance of these systems was analyzed with respect to present and future communications requirements using statistical VTS communication data. The systems are described with respect to hardware requirements and are characterized by the attainable data transmission rate. Cost estimates are furnished for all equipment not normally carried on commercial seagoing vessels, as well as the cost of modifying existing equipment. As a result of this study, the following conclusions are stated: (1) The introduction of a voice-based periodic position reporting scheme will quickly saturate available communication channels, (2) There are digital communication systems capable of expanding the capacity of existing communication channels.

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PREFACE

Coast Guard Vessel Traffic Service (VTS) facilities are established in several of the major U.S. ports, to prevent loss of life and property that could result from an accident involving ships. In performing the advisory service, a VTS relies heavily on radio communications to acquire the location of vessels and disseminate the information to other interested shipping. As the communication requirements change, the Coast Guard must be knowledgeable of the options available to meet the new requirements. Such expansion is projected to involve a change from voice reporting of position to automatic retransmission of the Loran-C coordinates from the ship's receiver.

To provide a basis for future system expansions and design, this study explores the communication channels available to maritime mobile service and the impact of change from voice to voice/data and data-only communication. The analysis performed under this study is divided into two tasks. Task I is a review of all frequency bands available for maritime service, identifying for each band all permissable transmission methods. Task II considers three candidate systems. The performance of these systems was analyzed with respect to present and future communications requirements using statistical VTS communication data.

The systems are described with respect to hardware requirements and are characterized by the attainable data transmission rate. Cost estimates are furnished for all equipment not normally carried on commercial seagoing vessels, as well as the cost of modifying existing equipment.

As a result of this study, the following conclusions are stated:

- The introduction of a voice-based periodic position reporting scheme will quickly saturate available communication channels.
- There are digital communication systems capable of expanding the capacity of existing communication channels. These range from the introduction of short burst messages of digital data onto existing voice channels, through the introduction of 'mid-channel' single sideband data channels which are transparent to the existing FM voice channels and which provide data capacities in excess of those required for the growth envisioned at this time.

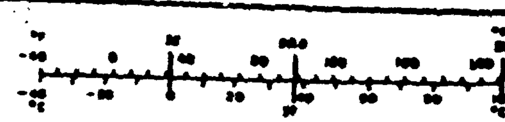
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

Coast Guard Vessel Traffic Service (VTS) facilities are established in several of the major U.S. ports. The purpose of the VTS is to prevent loss of life and property including environmental damage, that could result from an accident involving ships. Each VTS provides an advisory service to shipping in its service area. The advisories contain information concerning traffic conditions and hazards to navigation. In performing the advisory service, a VTS relies heavily on radio communications to acquire the location of vessels and disseminate it to other interested shipping.

Current VTS operations are centered primarily in the harbor areas. These operations make exclusive use of voice communications in the 156 to 160 MHz maritime mobile band. In some areas, the channels available in this band are already overcrowded. Looking into the future, it can be shown that there will be an increase in both the number of users communicating in the band and in the number of communications per user. It is anticipated that communications traffic at each VTS will also increase to keep pace with increases in shipping activity in the ports where they are established and as more precise information is required by the mariner.

Additionally, interest in offshore traffic management is rising. Although the requirements of such an effort are somewhat different from a port area VTS, the reliance on radio communications for effective operation appears to be the same. However, due to an extended range of communications from 20 nm (the practical limit of shore-based VHF communications) to 200 nm, the nature of the communication systems required for offshore traffic management would be substantially changed.

As the communication requirements change, the Coast Guard must be knowledgeable of the options available to meet the new requirements. Such expansion is projected to involve a change from voice reporting of position to automatic retransmission of the Loran-C coordinates from the ship's receiver. An expansion of required range sould require consideration of HF or satellite radio links to overcome the VHF line-of-sight limitation.

To provide a basis for future system expansions and design, this study explores the communication channels available to maritime mobile service and the impact of change from voice to voice/data and data only communication.

The analysis performed under this study is divided into two tasks:

- -TASK I : Spectrum and Transmission Analysis
- -TASK II : Baseline System Analysis.

TASK I is a review of all frequency bands available for maritime service, identifying for each band all permissible transmission methods. Using this information, preliminary estimates were made of the relative applicability of each band and transmission method to the present VTS coverage requirement of 0-20 nm, and to an extended coverage range for offshore traffic management of 0-200 nm. In performing this determination, emphasis was placed on the replacing of voice position reporting with the retransmission of digital data including Loran-C time differences or similar automatically obtainable position data.

As a result of this preliminary study review, the baseline systems analysis of TASK II was limited to VHF line-of-sight systems.

Under TASK II, three candidate systems were considered. The performance of these systems was analyzed with respect to present and future communications requirements using statistical VTS communication data. This analysis includes:

- -The density of users in existing VTS systems
- -The duration and repetition of communications with each user
- -The information transferred during check-in, check-out and advisory exchanges.

The systems are described with respect to hardware requirements and are characterized by the attainable data transmission rate. When the channel is co-occupied by voice, the effect of message length on expected data loss due to interference by voice transmissions has been analyzed. Each system is analyzed assuming current communications loads and increases of 10%, 25%, 50% and 100% in both the number of users and the time spent in communication with each user. Cost estimates are furnished for all equipment not normally carried on commercial seagoing vessels, as well as the cost of modifying existing equipment.

Candidate systems are:

- Systems which add data to existing narrow-band FM (NBFM) VHF voice equipment, including the possibility of voice and data co-existing in the same channel.
- Systems which employ an NBFM transmitter and receiver which has been modified to permit wide-band data modulation. This modification eliminates the bandwidth restriction placed on the first system by the voice channel audio filters. Again, data with voice and data only variants are possible.
- Systems which drop the requirements for NBFM modulation and the use of existing radios. Three variations of this approach are possible:
    - (a) the occupation of the entire allotted channel with directly modulated high-speed data
    - (b) the use of frequency-hopped FSK within the assigned channel to provide for multi-user random access communications
    - (c) the subdivision of the channel or the insertion between two existing channels of single-sideband channels in a manner currently being proposed for land mobile use.

As a result of this study, the following conclusions are stated:

- The introduction of a voice-based periodic position reporting scheme will quickly saturate available communication channels.
- There are digital communication systems capable of expanding the capacity of existing communication channels. These range from the introduction of

short burst messages of digital data onto existing voice channels through the introduction of 'mid-channel' single-sideband data channels which are transparent to the existing FM voice channels and which provide data capacities in excess of those required for the growth envisioned at this time.

This report is organized into six sections. The remaining five sections are described below:

2. - provides a summary of the frequency bands currently available to the maritime service along with the authorized classes of emission in each band and the applicability of the band to the VTS problem
3. - discusses the system requirements for the VTS communication and surveillance system
4. - describes the three candidate systems
5. - discusses the capacity of each system
6. - summarizes the conclusions of the author.

2. SPECTRUM AND TRANSMISSION ANALYSIS

2.1 Introduction

This section presents a summary of the frequency bands available to the maritime service, the authorized classes of emission in each band, and a preliminary assessment of the applicability of each band to the VTS problem. Due to the large number of frequency bands and even larger number of specific channel assignments within each band, the main body of this section does not attempt a detailed listing, but rather refers the reader to references W and X. These references list, in detail, frequencies allocated to the maritime mobile service, and the types of modulation permitted in each band. These regulations are referenced in the text by part, paragraph and page number (e.g. *2.106 pg.22*).

This summary divides the maritime mobile frequency allocations into the following categories:

- -VLF and LF low speed telegraphy frequencies
- -Groundwave over the horizon frequencies
- -HF ionospheric frequencies
- -Radio line-of-sight frequencies (e.g. VHF)
- -Satellite frequencies.

The authorized modulation techniques are divided into the following categories:

- -Voice
- -Low speed telegraphy (Morse code)
- -Narrow-band direct-printing data transmission systems
- -Wide-band telegraphy, facsimile transmission and special transmission systems.

2.2 Overview of the Maritime Frequency Allocations

Figure 2.1 is an overview of the maritime mobile radio frequency allocations. The low end of the maritime communication band technically starts at 110 kHz (*2.106 pg.22-23*). In practice, however, the frequencies below 490 kHz are

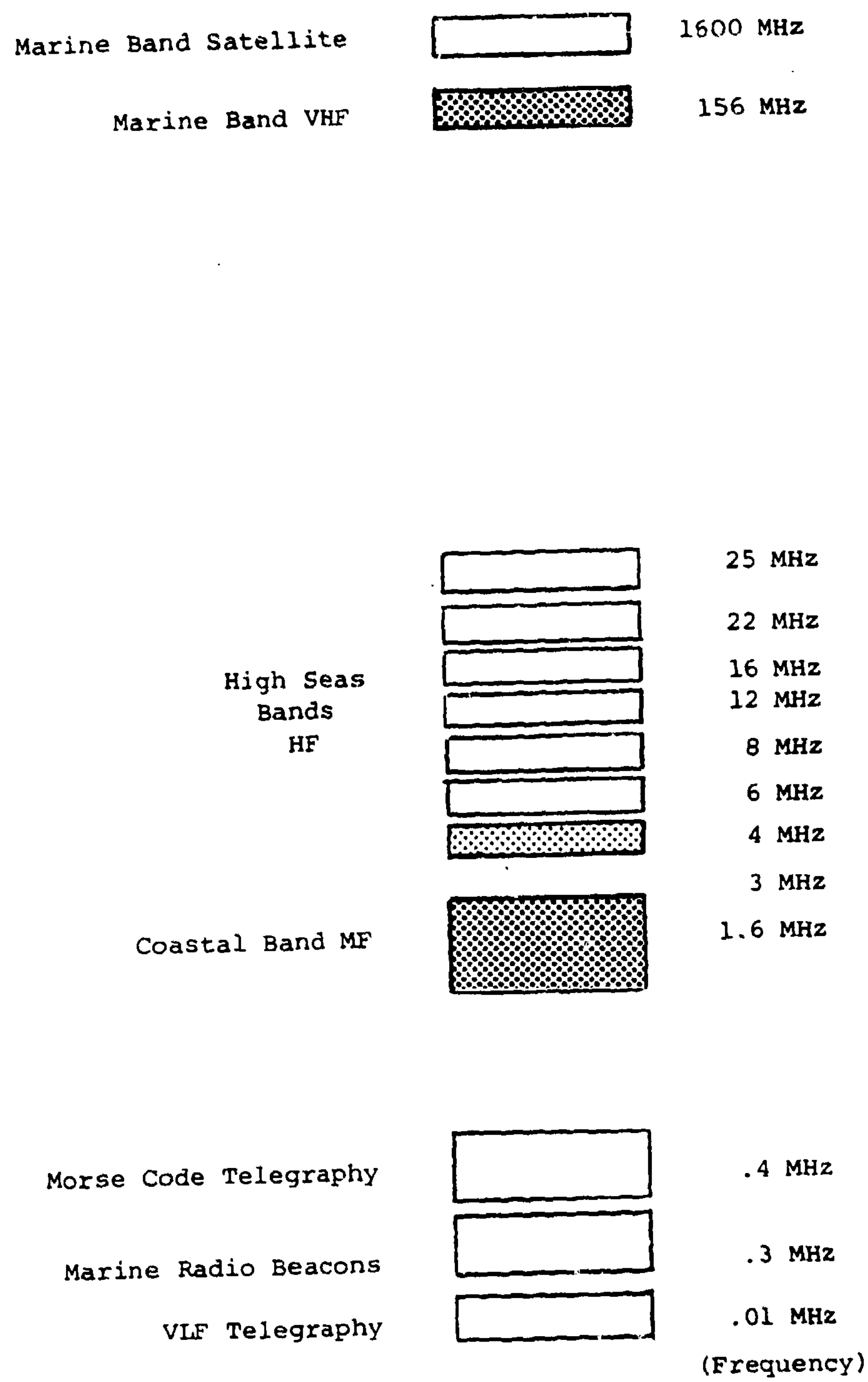

FIGURE 2.1 : OVERVIEW OF MARITIME MOBILE FREQUENCY ALLOCATIONS

limited to low-speed, keyed carrier communications (A-1 emissions), with telegraphy by means of on-off keying of an amplitude modulated audio frequency (A-2) permitted at the high end of the band (*81.132 pg.39-40 and 83.132 pg.150*).

The frequency bands extending from 2000 kHz to 2850 kHz (some 1600-2000 kHz available in Alaska) are the main coastal zone communication frequencies (*2.106 pg.24-25*). In these bands, provisions are made for virtually all modes of communications which can be supported by the media, including single sideband voice transmission, keyed carrier Morse code, and, of special interest to the VTS project, narrow-band direct-printing data transmission, wide-band data telemetry, facsimile and special transmission systems.

The HF bands grouped at 4 MHz, 6 MHz, 8 MHz, 12 MHz, 16 MHz, 22 MHz and 25 MHz comprise the primary high seas communication band (*2.106 pg.27-36A*). As for the coastal band, each of these high frequency bands has allocations which accomodate simple Morse code telegraphy, single sideband voice and a variety of data transmission systems.

The VHF marine band, including frequencies in the range of 156 MHz to 162 MHz *(2.106 pg.43-44)*, includes the main ship-to-coast communication channels. At these frequencies, line-of-sight communications is possible to a range of at least 20 nm, and commonly to distances of 40-70 nm where land-based antennas are positioned on top of high locations. Frequencies in the VHF band are channelized and provide for a variety of frequency modulated communications including voice and data transmission.

Frequencies in the microwave region *(2.106 pg.49,63,66)* are allocated for ship-to-satellite communication as well as satellite-to-ship transmissions. In general, the authorization of such frequencies is academic, as their use is dependent upon the availability of a suitable communications satellite. At the present time, coverage of the U.S. Coast areas (except the Gulf of Mexico) is provided by MARISAT satellites. These satellites provide for both voice and data communications between ships and fixed land stations on the East and West coasts (Santa Paula, California and Southbury, Connecticut).

In considering the use of the above frequency allocations and emission authorizations, it is necessary to realize that the assignment of communication channels reflects user needs at the present time, and can be changed to accomodate new systems. For example, at the present time, VTS systems in New York, New Orleans and Houston are allocated specific channels (*83.361 pg.200-A*) for providing services within their own radio protected areas. The important consideration for the present VTS communications study is not the present authorization for a given channel, but rather the accommodation within the frequency and emission allocation plans of specific types and bandwidths of modulations in the frequency bands able to support VTS communications.

2.3 Preliminary Assessments of Frequency Bands and Transmission Methods

A preliminary assessment for the suitability of the allocated frequency bands and transmission methods is made considering three factors:

- -The stated communication range
- -The anticipated vessel population, and hence system bandwidth requirements
- -The equipment costs.

2.3.1 Range Considerations

2.3.1.1 0-20 Nautical Mile Range

Within the 0-20 nm range, the VHF band should provide adequate communication range. As federal law presently requires the use of VHF communication wherever possible (*83.531.b.3.ii pg.194*) in preference to HF bands, there appears little option other than to use the VHF channels when operating within VHF range. In addition, those facilities which presently would not provide the full 20 nm range would most likely come under pressure to provide a VHF antenna height capable of providing 0-20 nm coverage, to prevent use of the 2 MHz band.

2.3.1.2 0-200 Nautical Mile Range

For the purposes of this report, the communications considered in this range shall be construed to be the range from the limits of VHF communications to the 200 nm limit. Within this range, MF, HF or satellite communications must be relied upon. Typically, communications in this range are accomplished using the 2 MHz to 3 MHz MF frequency band. This band is capable of providing communications out to a minimum range of 100 nm, and normally to the required 200 nm range. Increased reliability of communications in the 100-200 nm range could be obtained through the use of the 4 MHz high seas band.

If links which do not provide direct communications between the VTS station and the ship are considered, the use of other high-seas HF bands, relaying messages through the geographically disbursed HF communication nodes and/or the use of satellite systems may be considered. However, while these indirect systems will be capable of getting a message through, the data transmission techniques employed must be compatible with much larger, existing communication nets than those designed to communication directly between the ship and the VTS center. For example, a data link using the MARISAT satellite would be required to meet all of the technical specifications set up by the MARISAT Joint Venture, in addition to using a communications format which has been optimized for the VTS system.

2.3.2 Relative Performance of Voice and Data Systems

Studies of vessel population profiles indicate that a reasonably active VTS center must be capable of handling between 30 and 100 vessels. A detailed analysis of the VTS data message structure is presented in section 3.

To determine the applicability of various communication modes (e.g. voice, Morse code) a simplified position only configuration is assumed. This approach permits the relative effectiveness of each mode to be studied, without presupposing a message format. For a Loran-C position only system, data required from each ship to establish ship's position is assumed to be:

-The ship's identification

-Three Loran-C time differences

-Three signal quality indicators.

The estimated transmission times for voice, Morse code , narrow-band direct-printing teletype and wide-band digital techniques are shown in TABLE 2-1. To transmit position data by voice, under the assumption that the ship's radio operator is at watch prepared to transmit his information on request, a total message transmission time of 30 seconds is estimated. For Morse code, a transmission time of 27 seconds is estimated, narrow-band telegraphy estimate is 7.5 seconds; voice band digital techniques require the least time, with an estimated polling time of 78 msec to 2.5 seconds, depending on the time required to break the receiver squelch. The transmission times required for 10, 30, 50 and 100 vessels are shown in TABLE 2-2. This table shows that a 100-vessel system would require 50 minutes for a complete voice update of position, 45 minutes for Morse code, 12.5 minutes for narrow-band direct-printing telegraphy and .11 to 4.1 minutes for a voice band digital update. The relative slowness of voice and Morse code transmission, and the subsequent communication channel loading demonstrates the advantage of digital data transmission. Indeed, it could be argued that a 50-minute voice update rate would provide such stale position data that it would defeat the safety purposes of the system.

2.3.3 Estimates of the Relative Applicability of Various Transmission Frequencies and Formats

2.3.3.1 0-20 Nautical Mile Range

In the 0-20 nm range, the only logical and legal choice is to employ VHF communication frequencies. Further, as this region will probably contain the highest density of users, the very slow update time provided by a voice system point to the need to provide a means of digital transmission using an automatic or semi-automatic system. FCC Rules and Regulations, Volume IV, Paragraph 83.136.a.2.11 pg.152, permits the use of F3 (*2.201 pg.83*) frequency modulated (telegraph by keying an audio carrier) on some maritime mobile frequencies in the 156-162 MHz band, and it is assumed that similar authorizations could be obtained for VTS channels.

TABLE 2-1 : ESTIMATED POSITION REPORTING TIMES

(A) Voice (assuming ship's station at watch)....Estimated time = 30 seconds

Establish contact (including ID)
Read 3 time differences
Read 3 signal quality numbers

(B) Morse Code..................... ....Estimated time = 27 seconds

Message length:	9 letter ID + space x 2	=	20
	TD ident (2+space)x3	=	9
	TD value (7+space)x3	=	24
	End of Message	=	3
			56 characters

(25 words/min x 5 char/word = 125 characters/minute)

(C) Narrow-Band Direct-Printing Telegraphy......Estimated time = 7.5 seconds

Message length:	Call 9 digits	=	9
	Delay	=	(1 second)
	Response, 9 digits	=	9
	Type of msg, 8 digit	=	8
	TD ident (2+spc)x3	=	9
	TD value (7+CRLF)x3	=	27
	End of message	=	3
			65 Characters + 1 second delay

(Rate, 10 characters/second) (CRLF = 'carriage return, line feed)

(D) Voice Band Digital (2400 Baud).............Estimated time 78-2468 msec (dependent on squelch)

Call Message:	bits	time
break squelch & front porch		5-1200 msec
sync word	8	
request	16	
identification number	8	
check sum	8	
	(36)	
Response:		
break squelch & front porch		5-1200 msec
sync word	8	
identification	8	
Loran-C TD's	84	(7 digits) - 28 x 3
Loran Quality	24	(2 digits) - 8 x 3
	(124)	
Parity or check sum	4	

TOTAL BITS.............................164 (@2400 b/s) = 68 msec

TABLE 2-2 : VTS POSITION UPDATE TIMES

NO. OF VESSELS	VOICE (min)*	MORSE CODE (min)*	N-B D-P (min)*	VOICE BAND DIGITAL Long Squelch (sec)*	No Squelch (sec)*
10	5	4.5	1.25	0.4	0.01
30	15	13.5	3.75	1.29	0.03
50	25	22.5	6.25	2.05	0.05
100	50	45	12.5	4.1	0.11

*Update time for total number of vessels

2.3.3.2 0 - 200 Nautical Mile Range

The most applicable system for the 0-200 nm range appears to be the MF 2 MHz band. Paragraph 83.132.a.l.i of the Radio Regulations provides for the transmission of wide-band telegraphy, etc. on the frequency bands between 2070 kHz and 2080 kHz. The major question raised regarding the use of this frequency is the reliability with which the 200 mn limit can be reached, especially near the periods of local noon and local midnight.

A secondary, or backup set of frequencies could be considered, which used both the 2 MHz and 4 MHz band. However, the 4 MHz band ionospheric skips can provide some fairly long ranges (4000 nm) which could create an interference problem.

The use of the 4 MHz - 25 MHz high-seas bands to fill in a small area between the limits of the 2 MHz coverage and the 200 nm limit is considered undesirable, due to its inconsistency with the nature of the communications assigned to these channels, i.e., long range high-seas communications through centralized communications nodes. This use of satellite communication as the main communication link out to 200 nm is considered least desirable, due to high equipment and channel usage costs.

Meteor burst communication may be used to fill in the line-of-sight 200 nm range. The use of meteor burst communications is the subject of a separate, parallel study.

As a result of a preliminary study review, a decision was made to limit further system analyses to systems which would operate over VHF communication channels. Thus, the baseline system analysis pursued in the remainder of this report considers systems and data modulation techniques that transmit the digital VTS data over VHF links. By the nature of these systems, it is assumed that the messages are of a short, or burst, nature. The three baseline systems analyzed and their variants are discussed in section IV.

3. SYSTEM REQUIREMENTS

3.1 System Configuration

An overview of a digital VTS system is shown in Figure 3-1 . The components of the system are divided between the VTS center and the vessel. The block diagram indicates that data communications are considered an addition to voice communication, and not a replacement. This is necessary due to the variety of nonstandard messages which are possible, and to allow for users that are not equipped with a digital communications capability. The portion of the system located at the VTS center is assumed to be controlled by the VTS computer or an intelligent peripheral driven by the computer. The vessel-based equipment consists of voice communication capability, either augmented with or supplemented by a digital communication capability.

Two key elements in the system are:

-The computer at the VTS center

-The microprocessor controller in the vessel.

These two elements permit the system to use the available communication time in an efficient manner. For example, the VTS center is not constrained to respond to a vessel messages in a sequential fashion. At the VTS, it is possible to accept and process many vessel messages in a random order, relying on the computer at the VTS center to present the information to the VTS watchstander in an organized manner.

At the vessel, the microprocessor can control access to the communication links, minimizing the possibility of a transmission interfering with a transmission currently in progress, and to provide identification and position data without operator intervention. The microcomputer capability on the vessel also allows for a wide variety of message input and data display techniques. Finally, working together, the computers can control the handshaking between the VTS center and a vessel, providing automatic acknowledgement of messages which are received correctly, and automatic requests for retransmission of messages garbled or missing.

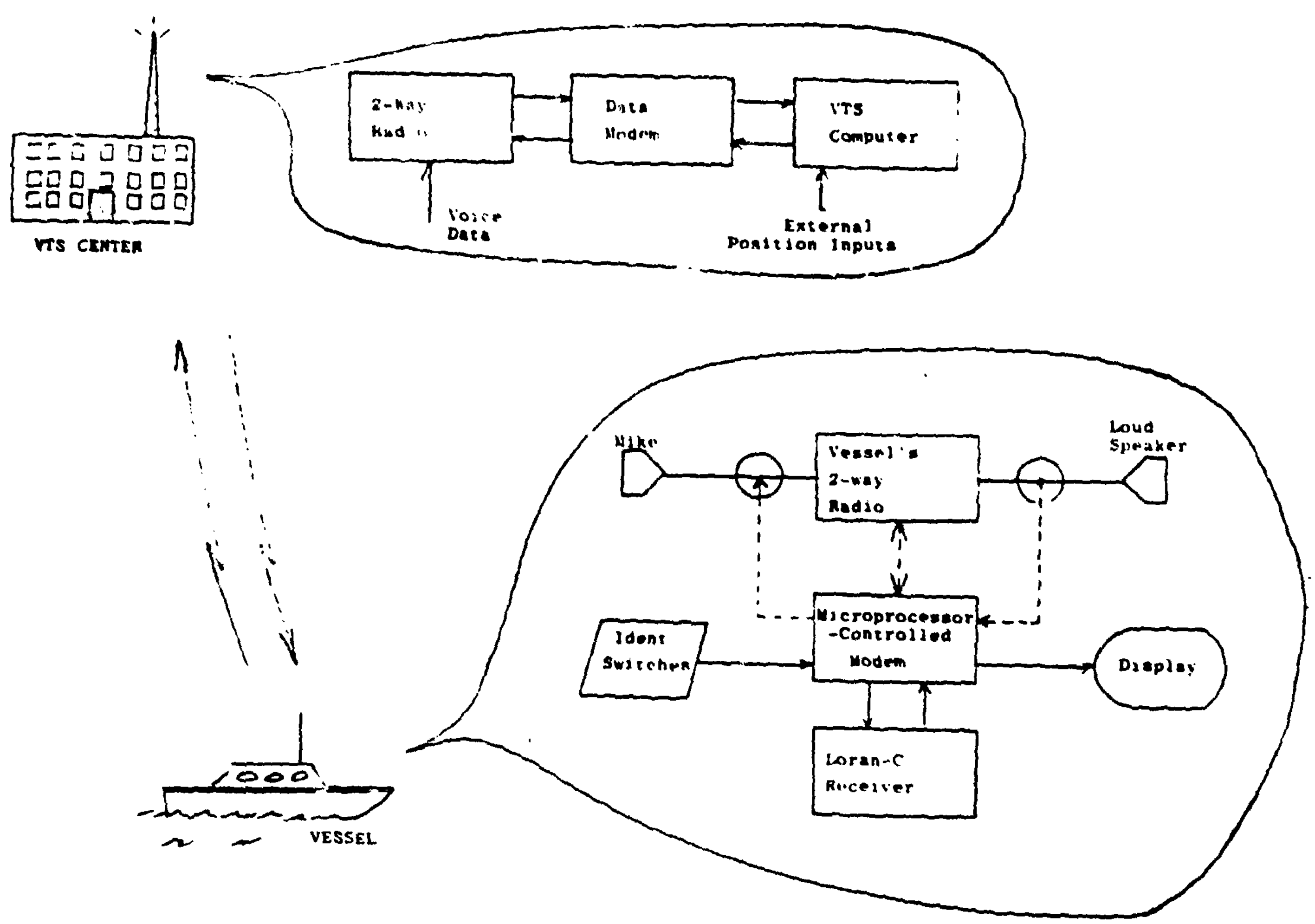

FIGURE 3-1 : OVERVIEW OF VTS DIGITAL DATA SYSTEM

3.2 Voice Channel Characteristics

To obtain design information against which to analyze the effect of voice transmissions on digital data transmissions in the same channel, and to structure equivalent digital messages, it was necessary to analyze the statistics of the communications traffic at existing VTS centers. These data are contained in references A through F, with the bulk of the statistics coming from reference C. Data requirements were extracted from references A and B.

Information concerning VHF channel usage, communication characteristics and characteristics of transaction types are listed in tables 2-2, 2-3 and 2-4 of reference C. For convenience, these tables are reproduced in this report as TABLE 3-1 and TABLE 3-4. To determine the effect of voice communication on digital data, it is necessary to know the amount of unused channel time per hour, as well as mean time between voice transmissions. The amount of unused time on the channel is, to a first approximation, the amount of time available for the transmission of digital data.* The mean time between voice messages is used to compute the probability that a digital message of a given length can be successfully completed between voice transmissions.

TABLE 3-1 presents statistics for four VTS centers, Houston-Galviston (HOU-GAL), New Orleans, Louisiana (NOLA), Puget Sound (PS) and San Francisco (SF). TABLE 3-1b defines a transaction to be the total time during which a VTS watchstander is involved with a single vessel transaction. Therefore, each transaction may include several transmissions from the VTS center to the vessel and from the vessel to the VTS center. In addition, a transaction also includes 'dead time,' which is defined as the time during which no signal is being transmitted, but the transaction is still in progress, with the vessel or the VTS watchstander assembling information for transmission. TABLE 3-2 is an expansion of TABLE 3-1.

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*In practice, this time is reduced, due to the occurrence of dead time too short to hold a structured digital message and the loss of data due to the initialization of a voice transmission during a data message.

TABLE 3-1a. VHF RADIO CHANNEL USE

	HOU-GAL	NOLA	PS	SF
Percent channel utilization	54	20	30	12
Number of channels	1	3	1	1

TABLE 3-1b. COMMUNICATIONS CHARACTERISTICS

Average Hourly Characteristic	HOU-GAL	NOLA	PS	SF
Number of transactions	96	45	46	20
Number of transactions per vessel	3.2	0.8	1.2	2.5
Time per Transaction (sec)	22	53	30	21
"Dead time" per transaction (sec)	12	29	6	5
"Dead time" per transaction (%)	55	55	20	24
Communication time per vessel (sec)	70	42	35	53
Percent vessel-initiated transactions	90	91	73	76

In TABLE 3-2, the vessels per hour was computed by dividing the number of transactions per hour by the number of transactions per vessel. Column D, the channel time in seconds per transmission, was computed as the difference between the total transac ion time and dead time. Column E, the total seconds of channel usage per hour, is a product of the number of transactions per hour times the channel time per transaction. Column G, the mean time between message segments, or physically the time between the end of one voice transmission as defined by the operator releasing the microphone transmit key, and the start of another, defined as the depressing of the transmitting key. For computing Column G, the number of microphone keyings of significance to this analysis is considered to be twice the number of transactions per hour, with the assumption that each transaction contains two segments separated by the dead time indicated as Column C. The interval of time during which a transaction will be initiated is assumed to be limited to the free time indicated in Column F, as it is assumed that a watchstander will not purposefully key his microphone while the channel is busy. This yields a mean time between message segments as the ratio between the free time per hour divided by twice times the number of transactions per hour.

The effect of growth in the VTS system is reflected in TABLE 3.3. Here, using the numbers for HOU-GAL (busiest VTS in terms of mean time between message segments) the effect of growth in traffic (vessels/hour) and communication duration (channel time in seconds/transmission) are calculated to obtain the resulting free time per hour and mean time between message segments. TABLE 3-2 and TABLE 3-3 show that current mean time between message segments varies from 14 to 100 seconds, and that under growth of 10% to 50%, the mean time at HOU-GAL reduces from 14 to 4 seconds and finally, at a 100% growth in both number of vessels and duration of communications, the single channel available at HOU-GAL will have an anticipated negative free time of 240 seconds (and therefore a meaningless mean time between message segments).

The effect of the mean time between message segments on the probability of a digital message being received without interruption by a voice transmission is

TABLE 3-2 : VOICE CHANNEL STATISTICS DERIVED FROM TABLE 3-1

LOCATION	VESSELS PER HOUR	(A) TRANSACTIONS PER HOUR	(B) COMMUNICATION TIME SEC/TRAN	(C) DEAD TIME SEC/TRAN	(D) CHANNEL TIME SEC/TRAN	(E) TOTAL SEC/HR	(F) FREE TIME PER HOUR	(G) MEAN TIME BETWEEN MSG. SEG. (SEC)
HOU-GAL	30	96	22	12	10	960	2640	14.
NOLA*	56	45/3=15	53	29	24	360	3240	108
PS	38	46	30	6	24	1104	2496	27
SF	8	20	21	5	16	320	3280	82

*three equally used channels

TABLE 3-3 : VOICE CHANNEL STATISTICS FOR HOU-GAL FROM TABLE 3-2, EXPANDED FOR GROWTHS OF 10%, 25%, 50% and 100%

CURRENT	30	96	22	12	10	960	2640	14
+10%	33	106	24	13	11	1166	2434	11
+25%	37.5	120	28	15	13	1560	2040	8.5
+50%	45	144	33	18	15	2160	1140	4
+100%	60	192	44	24	20	3840	----	0

calculated under the assumption that the initialization of a given voice transmission will occur randomly during the free channel time.* Under this assumption, the probability density function for messages initiated at a given time is Poisson distributed. Further, the probability that n events will occur after T seconds of dead time is given by the gamma distribution:

$$F\ (T,n) = 1 - e^{-\lambda T} \left\{ 1 + \lambda T + \ldots + \frac{(\lambda T)^{n-1}}{(n-1)!} \right\}$$

T = wait time

λ = mean waiting time

n = number of events

As che occurrence of a single event terminates the dead time, n=1, and:

$$P\ (T) = 1 - e^{-\lambda T}\ (1 + \lambda T)$$

Values for the gamma distribution for digital message length of 0-14 seconds and for the mean time between message segments (λ) listed in TABLE 3-2 and TABLE 3-3 are shown in Figure 3-2.

Figure 3-2 indicates the probability of losing a digital message due to the start of a voice message for digital messages of varying lengths. Using this figure, it is seen that approximately 1 out of 300 (1-second) messages will be lost due to the initialization of a voice transmission under assumed conditions presently expected at HOU-GAL VTS (m-14 sec). The effect of a lost digital message will be to further reduce the channel capacity, as detection of the incomplete message and/or the lack of acknowledgement of the message will cause the sender to resend the message. Figure 3-2 does not limit the amount of digital data that can be sent to a vessel from the VTS center, but rather

*This assumption is perhaps more strict than the actual situation in the VTS system. It may be argued that it is more probable for a ship to call in as soon as the channel clears, as the result of a cue formed while a transaction was in progress. If a higher probability of an immediate transmission is assumed, it implies that the free time periods would come in longer undisturbed blocks than under the present assumption.

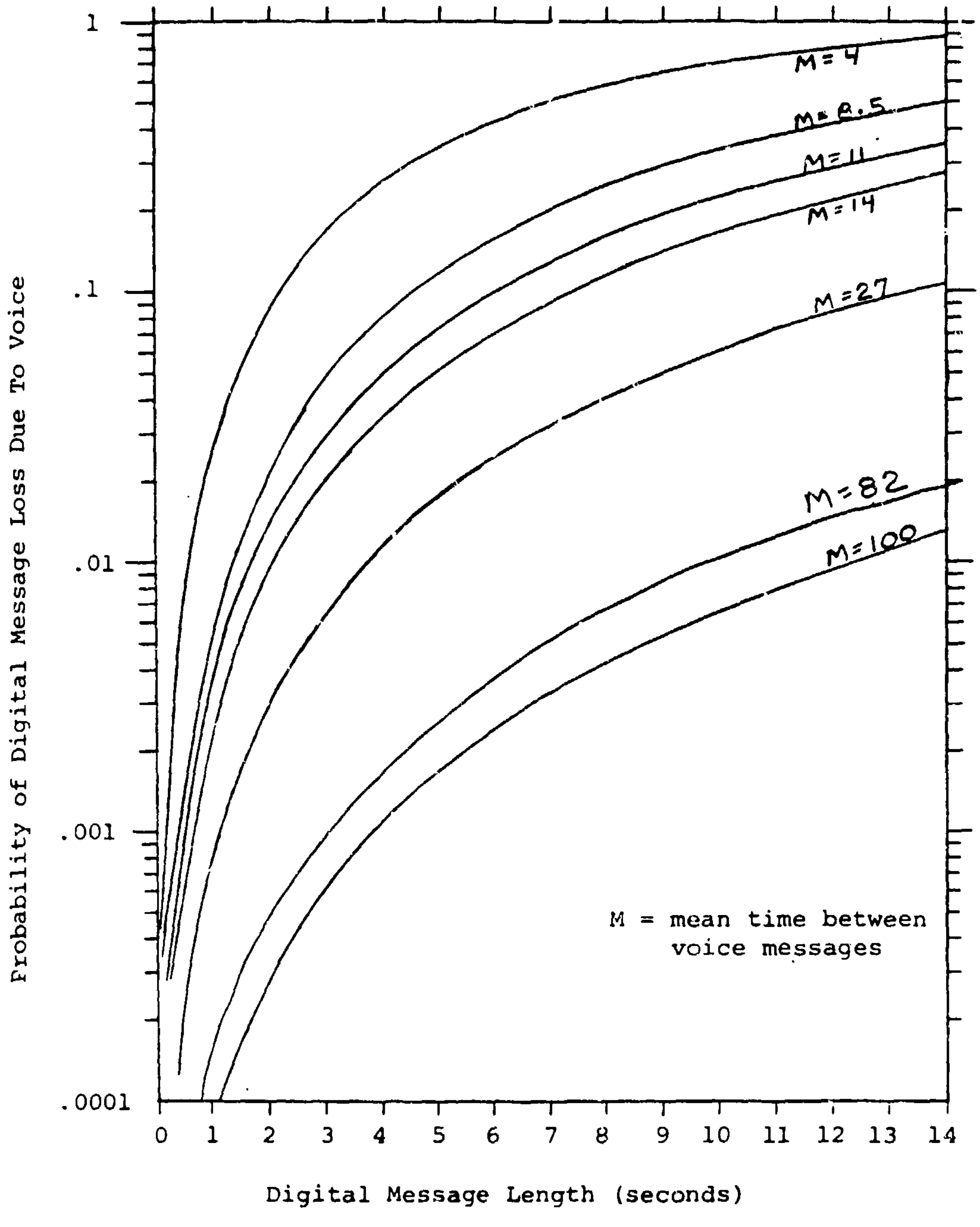

Figure 3-2 : PROBABILITY OF DIGITAL MESSAGE LOSS DUE TO VOICE VS DIGITAL MESSAGE LENGTH IN SECONDS limits the maximum length into which a longer message must be partitioned to assure that the various segments can be received with a given probability of voice interference. The total amount of data which is to be transmitted is primarily controlled by the channel free time.

TABLE 3-4 lists the four types of messages communicated between vessels and the VTS centers. These are:

-Advisories

-Check-in

-Check-out

-Other.

In implementing a digital system, it is assumed that the digital traffic will handle the advisory, check-in and check-out messages; and further, that messages now listed as 'other' are of a nature that cannot be readily accommodated in the digital link. Check-in and Check-out messages will grow in proportion to the number of ships participating in the VTS. As the number of ships in the system grows, it is reasonable to expect each ship to receive more frequent and lengthy advisories from the VTS. For this reason, frequency of advisories are assumed to grow in proportion to both the number of ships in the system and the frequency with which each ship accesses the VTS for advisories. To accomodate both an increase in the number of ships and the length of communications with each vessel, growth factors of 10%, 25%, 50% and 100% have been applied to both variables. These extrapolated statistics are shown in matrix form in TABLE 3-5. This table shows that the biggest impact with growth will be in the total number of advisories. For HOU-GAL, a 100% increase in the number of ships using the VTS implies a change from 6.7 to 13 Check-in's per hour, while the number of advisories increases at 4 times that rate, from 74 to 296 per hour. Increases in the length of the advisory messages are not considered in TABLE 3-5, but are considered parametrically in section V.

3.3 Message Requirements

To determine the content of each type of message, the sample messages contained

TABLE 3-4. CHARACTERISTICS OF TRANSACTION TYPES

TYPE	AVERAGE LENGTH OF TRANSACTION (SEC.)			
	HOU-GAL	NOLA	PS	SF
Advisories	20	56	34	21
Check-ins	76	88	27	25
Check-outs	21	24	17	23
Other	8	34	46	16

	FREQUENCY OF TRANSACTION TYPES (%)			
	HOU-GAL	NOLA	PS	SF
Advisories	77	58	33	15
Check-ins	5	13	37	42
Check-outs	7	9	18	7
Other	11	20	12	36

TABLE 3-5. CHANGES IN NUMBER OF TRANSACTIONS WITH USER AND FREQUENCY OF COMMUNICATION CHANGES OF 0%, 10%, 25%, 50% and 100%

			Frequency of Position/Situation Advisories				
NUMBER OF SHIPS	CHECK-IN	CHECK-OUT	CURRENT	+10%	+25%	+50%	+100%
(Percent of Current Commun.)	*(7%)*	*(5%)*	*(77%)*	*(85%)*	*(96%)*	*(116%)*	*(154%)*
Current: 30 (96 trans/hr)	6.7	4.8	74	81	93	111	148
+10% (33 ships)	7.4	5.3	81	89	102	122	163
+25% (37.5 ships)	8.4	6	93	102	116	139	185
+50% (45 ships)	10	7.2	111	122	140	166	222
+100% (60 ships)	13	9.6	148	163	185	222	296

in both the New York and Prince William Sound VTS operating manuals (ref. A and B) were analyzed. These messages, along with the time required to read the message at a moderate rate and the elements which comprised the message are contained in TABLE 3-6. This table also contains typical "other" or special messages which are not easily accommodated as structured digital messages. The time required to read each message was measured to compare it to the mean time shown for Check-in, Check-out and advisory messages in TABLE 3-4. Although the times vary widely, the sample messages seem to be typical.

From the sample messages, five prototype digital messages have been constructed, three vessel messages and two VTS messages. The vessel messages are:

-a check-in

-a followup message

-a check-out

The VTS messages are:

-request for status

-general acknowledge message to acknowledge check-in, status request, and check-out messages.

In constructing these messages, it was necessary to assume a coding for each of the message elements. The tradeoff here is between minimizing message transmission time and transmitting data in a form which is easy for the vessel and the VTS to interpret. For example, referring to the check-in message shown in TABLE 3-7a, items such as the sync word, message type, the check sum, as well as the item separators are system control characters and may be specified without concern for the operator's ability to interpret them. The next level of characters are those which can be abbreviated through convention. For example, vessel type can be limited to several classes of vessel and abbreviated in a standard format. Similarly, status, cargo type, communication/navigation capability can be shortened by using agreed upon abbreviations. Items such as the vessel draft, length, time parameters, location parameters and waypoints are already compact, as they are provided according to a standard measurement system of either feet or, in the case of location parameters, Loran-C time difference numbers. The vessel ID is

TABLE 3-6a : INITIAL REPORT TRANSACTION

Time to read: 44 seconds

SITUATION:	A vessel is approaching Hinchinbrook Entrance en route to Jackson Point Terminal.
CALL UP:	VALDEZ TRAFFIC, this is the American Eagle, Over.
REPLY:	American Eagle, this is VALDEZ TRAFFIC, Over.
MESSAGE:	VALDEZ TRAFFIC, this is the tank vessel American Eagle, draft 36 feet. We are 10 miles southwest of Seal Rocks, ETA Schooner Rock 0800, SOA 16 knots, ETA Jackson Point 1300 via the TSS. All operations are normal, we are in ballast with no hazardous materials on board. We have a back-up VHF-FM on Channel 13. Over.
REPLY ADVISORY:	American Eagle, VALDEZ TRAFFIC, we have the T/V Jenniver L. outbound at Bligh Reef. You should meet in the vicinity of Montague Point, OVER.
REPLY:	This is American Eagle, Roger, OUT.

MESSAGE:	VALDEZ TRAFFIC	Call
	this is the tank vessel	Vessel Type
	American Eagle	Vessel ID
	draft 36 feet.	Draft
	We are 10 miles southwest of Seal Rocks	Location
	ETA Schooner Rock	Waypoint #1
	0800	ETA waypoint #1
	SOA 16 knots	Speed
	ETA Jackson Point	Waypoint #2
	1300 via TSS	ETA waypoint #2
	All operations are normal	Condition
	we are in ballast with no hazardous materials on board	Cargo type
	We have a back-up VHF-FM on Channel 13, Over.	Communications capability
REPLY ADVISORY:	American Eagle,	Call
	VALDEZ TRAFFIC	ID
	we have the T/V	Vessel type
	Jennifer L.	Vessel ID
	outbound at Bligh Reef.	Location
	You should meet in the vicinity of Montague Point, Over.	Meeting Point

TABLE 3-6b : INITIAL REPORT #2 TRANSACTION

Time to read: 40 seconds

SITUATION:	A tug with tow is entering the VTS area from Whittier outbound for Seattle.
CALL UP:	VALDEZ TRAFFIC, this is the American Tug, Over.
REPLY:	American Tug, this is VALDEZ TRAFFIC, OVER.
MESSAGE:	VALDEZ TRAFFIC, this is the towing vessel American Tug abeam Smith Island with one rail barge in tow. I will enter the TSS off Smith Island at 0900. My draft is 16 feet. Barge draft is 20 feet. Speed of advance is 7 knots, overall length of tow 600 feet. No hazardous materials on board. No other communications capability. Over.
REPLY ADVISORY:	American Tug, VALDEZ TRAFFIC, Roger. There is no known traffic in that area at the present time. OVER.
REPLY:	This is the American Tug, Roger, Out.

MESSAGE:	VALDEZ TRAFFIC	Call
	this is the towing vessel	Vessel type
	American Tug	Vessel ID
	abeam Smith Island	Location
	with one rail barge in tow	Tow load (tug only)
	I will enter the TSS of Smith Island	Waypoint #1
	at 0900	ETA waypoint #1
	My draft is 16 feet	Draft
	Barge draft is 20 feet	Barge draft (tug only)
	Speed of advance is 7 knots	Speed
	Overall length of tow, 600 ft.	Overall Length of tow (tug only)
	No hazardous materials on board	Cargo type
	No other communications capability, Over.	Communications Capability
REPLY ADVISORY:	American Tug,	Call
	VALDEZ TRAFFIC,	ID
	Roger.	Acknowledgement
	There is no known traffic in that area at the present time, OVER.	Advisory

TABLE 3-6c: FOLLOW-UP REPORT TRANSACTION

Time to read: 22 seconds

SITUATION: Vessel passes a reporting point.

CALL UP: VALDEZ TRAFFIC, this is the American Eagle, Over.

REPLY: American Eagle, this is VALDEZ TRAFFIC, Over.

MESSAGE: VALDEZ TRAFFIC, American Eagle. I have Schooner Rock abeam and am in the northbound lane and decreasing speed to 10 knots. Revised ETA at Jackson Point is 1600. I have the Jennifer L. in sight. Over.

REPLY: American Eagle, this is VALDEZ TRAFFIC, Roger, Out.

MESSAGE:	VALDEZ TRAFFIC	Call
	American Eagle	Vessel ID
	I have Schooner Rock abeam and am in the northbound lane	Location
	and decreasing speed to 10 knots	Velocity
	Revised ETA Jackson Point	Waypoint
	is 1600	ETA waypoint
	I have the Jennifer L. in sight, Over.	Traffic sighted

Time to read: 15 seconds

SITUATION: Vessel enters the TSS

CALL UP: VALDEZ TRAFFIC, This is the American Tug, Over.

REPLY: American Tug, this is VALDEZ TRAFFIC, OVER.

MESSAGE: This is American Tug. Have entered southbound lane at Smith Island and increased speed to 9 knots. OVER.

REPLY: This is VALDEZ TRAFFIC, Roger, Out.

MESSAGE:	This is American Tug.	Vessel ID
	Have entered southbound lane at Smith Island	Location
	and increased speed to 9 knots. Over.	Velocity

TABLE 3-6d : FINAL REPORT TRANSACTION

Time to read: 23 seconds

SITUATION:	Vessel leaving the TSS
CALL UP:	VALDEZ TRAFFIC, this is the American Tug, Over.
REPLY:	American Tug, this is VALDEZ TRAFFIC, Over.
MESSAGE:	VALDEZ TRAFFIC, this is American Tug abeam Schooner Rock. I am leaving the TSS at the present time. I will cross the TSS in Hinchinbrook Entrance in 10 minutes and proceed southeasterly from Cape Hinchinbrook. Over.
REPLY:	American Tug, this is VALDEZ, Roger, Out.

MESSAGE:	VALDEZ TRAFFIC,	Call
	this is American Tug	Vessel ID
	abeam Schooner Rock.	Location
	I am leaving the TSS at the present time.	ETA exit
	I will cross the TSS in Hinchinbrook Entrance	Waypoint, exit
	in 10 minutes	ETA waypoint, exit
	and proceed southeasterly from Cape Hinchinbrook. Over.	Waypoint #2

Time to read: 12 seconds

SITUATION :	Vessel anchoring in the VTS area
CALL UP:	VALDEZ TRAFFIC, this is the Kristen Anne, Over.
REPLY:	Kristen Anne, this is VALDEZ TRAFFIC, Over.
MESSAGE:	This is Kristen Anne. We have anchored in Tatitlek Narrows off Ellamar, Over.
REPLY:	This is VALDEZ TRAFFIC, Roger, Out.

MESSAGE:	VALDEZ TRAFFIC	Call
	this is Kristen Anne.	Vessel ID
	We have anchored in Tatitlek Narrows off Ellamar. Over.	Status/Location

TABLE 3-6e : SPECIAL REPORTS

SITUATIONS: Self-explanatory

NEW YORK TRAFFIC, This is the tug Edsel Filbert. I am maneuvering with difficulty with two light barges ahead in a heavy wind. Inform any traffic I might meet that I will need a wide berth.
Over.

NEW YORK TRAFFIC, This is the freighter Jet Trader. Visibility entering Ambrose Channel is 100 yards, and my radar is inoperative.
Over.

TABLE 3-7a : PROTOTYPE DIGITAL MESSAGE: CHECK-IN MESSAGE (AS)

	# of characters (alpha-numeric) plus item separator
SYNC WORD	5
TYPE OF MESSAGE	2
VESSEL ID (NAME)	31
VESSEL TYPE	4
DRAFT	3
LENGTH	4
LOCATION (4 Loran-C + DS at 7 digits each)	29
STATUS (underway, holding, docking, etc)	2
ESTIMATED STATUS CHANGE TIME (xxxx)	5
VELOCITY + DIRECTION	5
CARGO TYPE	4
Additional for Tug:	
Draft of Barge	3
Total Length	4
Number of Barges	2
COMMUNICATION/NAVIGATION CAPABILITY	3
WAYPOINT #1 (2 TDs @7 digits)	15
ETA WAYPOINT #1 (time)	5
WAYPOINT #2 (2 TDs @7 digits)	15
ETA WAYPOINT #2 (time)	5
CHECK SUM + EOT	4
	150 characters
Assuming ASCII code : 10 bits/character	x 10
	1500 bits

TABLE 3-7b : PROTOTYPE DIGITAL MESSAGE : Follow-up Report (B3)

	# of characters (alpha-numeric) plus item separator
SYNC WORD	5
TYPE OF MESSAGE	2
VESSEL ID ASSIGNED	4
LOCATION (4 Loran-C + DS at 7 digits each)	29
STATUS	2
EST STATUS CHANGE TIME	5
VELOCITY AND DIRECTION	5
WAYPOINT #1	15
ETA WAYPOINT #1	5
WAYPOINT #2	15
ETA WAYPOINT #2	5
CHECK SUM + EOT	4
	90 characters
Assuming ASCII code : 10 bits/character	x 10
Assuming ASCII encoding:	900 bits
Assuming binary encoding:	360 bits

TABLE 3-7c : PROTOTYPE DIGITAL MESSAGE: Check-Out Message (CS)

	# of characters (alpha-numeric) plus item separator
SYNC WORD	5
TYPE OF MESSAGE	2
VESSEL NAME	31
STATUS (Leaving System)	2
CHECK SUM + EOT	4
	44 characters
Assuming ASCII code : 10 bits/character	x 10
	440 bits

TABLE 3-7d : PROTOTYPE DIGITAL MESSAGE : Request for Status (A-VTS)

		# of characters (alpha-numeric) plus item separator
SYNC WORD		5
TYPE OF MESSAGE (request for status)		2
VESSEL ID ASSIGNED		4
NUMBER OF VESSEL STATUS REPORTS TO FOLLOW		3
TRAFFIC DATA RETURNED TO VESSEL		
Vessel Identification	31	
Vessel Type	4	
Location	15	
Time to meeting	5	
Position of meeting	15	
Velocity	3	
	(73)	
CHECK SUM + EOT		4

Length with no traffic data..........................18 characters

Assuming ASCII code : 10 bits/character x 10

910 bits

ONE VESSEL	91 characters	910 bits
THREE VESSELS	237 characters	2370 bits
TEN VESSELS	748 characters	7480 bits
THIRTY VESSELS	2208 characters	22080 bits

TABLE 3-7e : PROTOTYPE DIGITAL MESSAGE : Acknowledge, Check-in, Status Request and Check-Out Messages; VTS to Vessel

	# of characters (alpha-numeric) plus item separator
SYNC WORD	5
TYPE OF MESSAGE	2
VESSEL NAME	31
ASSIGNED VESSEL ID	4
CHECK SUM + EOT	4
	46 characters
Assuming ASCII code : 10 bits/character	x 10
	460 bits

the most variable parameter, as it is assumed that ship names are selected by the ship owner. The use of alpha-numeric characters in the prototype VTS messages was strongly influenced by the desire to send actual vessel names and identifications in easily readable form between the VTS and a vessel. Although it is possible to quickly address a number of vessels using a shortened temporary ID number, the visual identification of a vessel listed in an advisory will be made by observing vessel type and the name printed on the vessel.

For purposes of standardization and to provide an upper bound on message length in terms of bits, the messages presented in this report are expressed both in terms of the number of alpha-numeric characters necessary to transmit the message and the number of bits required when each character is encoded in ASCII code, assuming 10 bits per character. In normal cases, the number of characters assigned to each parameter can be shortened to the actual length, as it is assumed each item is separated by a separator character. Therefore, vessels with shorter names than the maximum 30 characters allowed would require less transmission time. The message length may also be reduced by the introduction of a modified ASCII code, sending for example, only capital letters and numbers, and further by the elimination of the start, parity and stop bits. This would enable each character to be sent with 6 rather than 10 bits per character. The effect of shortening the message can easily be determined. For the balance of this report, message lengths and associated communication times will be based on 10 bits per character ASCII transmission of alpha-numeric information.

The check-in message shown in TABLE 3-7a provides basic vessel data, including name, vessel type, physical size. This is the longest vessel-to-VTS message, a fact which is in agreement with TABLE 3-1c. Following check-in to the system, the VTS assigns the vessel an abbreviated ID to shorten follow-up communications. Once a vessel has checked into the system and its presence has been acknowledged, automatic follow-up communications from the vessel are issued in response to either a vessel request to the VTS to provide advisory information, or as a vessel response to a VTS request for a vessel position report. A vessel follow-up report is shown in TABLE 3-7b. It includes the current vessel location, status, estimated time to change in status, current velocity including direction and two anticipated waypoints including the estimated time of arrival at those waypoints. Prior to checking out of the VTS system, the vessel sends a vessel check-out message. A check-out message, which includes the vessel's intent to check out of the system and the vessel's full alpha-numeric name, is shown in TABLE 3-6b.

The VTS-generated advisory and request for status message is shown in TABLE 3-7d. With this message, the VTS transmits to the addressed vessel the identification, type, location and expected time and 'passage' location of the addressed vessel with other vessels in the area. The number of vessels included in each VTS advisory report is variable and dependent upon the density of traffic in the area as well as the display capability of the vessel receiving the message. TABLE 3-7d divides the VTS advisory message into two parts, the first is a minimal length 18-character message returned when no vessel status information is issued. The second shows the number of characters for the number of vessel status contained in the message. Message lengths are shown for reports containing 1, 3, 10 and 30 vessels. The second message type transmitted from the VTS to the vessel is an acknowledgement message used primarily to acknowledge check-in, by assigning the vessel a temporary identification number, and for check-out. This message may also be used as a NACK message, to indicate that a message from the identified vessel was not successfully received by the VTS.

4. DATA TRANSMISSION TECHNIQUES

The data messages described in section 3.3 are communicated between the vessel and the VTS using digital data modulation techniques. This requires the serial transmission of the digital data employing any one of a variety of data modulation schemes. The time structure of a typical message is shown in Figure 4-1. Prior to keying the transmitter, the data modulator checks for channel availability. If the channel is clear and stays clear for a short but random interval, the transmitter is keyed, causing the transmission of a data carrier. The length of time this carrier is kept on is predetermined and dependent on the radio link. If the selected system includes radios with noise squelch circuits, the initial portion of the message must be long enough to assure that the squelch will break, permitting the data to reach the receiver's data demodulator. Next a synchronization word is sent to synchronize the receiver characters and message clocks with the transmitter. This, in turn, is followed by an identification word and, finally the body of the message. The message is followed by error check characters which are provided to increase confidence in the received data.

Three data transmission system configurations are considered in this report. Each provides different data transmission rates, varying spectrum requirements and varying degrees of hardware complexity. The techniques are:

- The transmission of the digital data through voice channels of an existing narrow-band FM radio
- The transmission of wide-band data using the existing narrow-band FM radio, but direct interface with the modulator and demodulator
- The use of independent transmitters and receivers designed specifically for data transmission.

4.1 Transmission of Data Over a Narrow-Band FM Voice Channel

A block diagram of a system which transmits data over a narrow-band FM voice channel is shown in Figure 4-2. With this approach, the required data are modulated to frequencies in the voice audio range, and fed into the transmitter

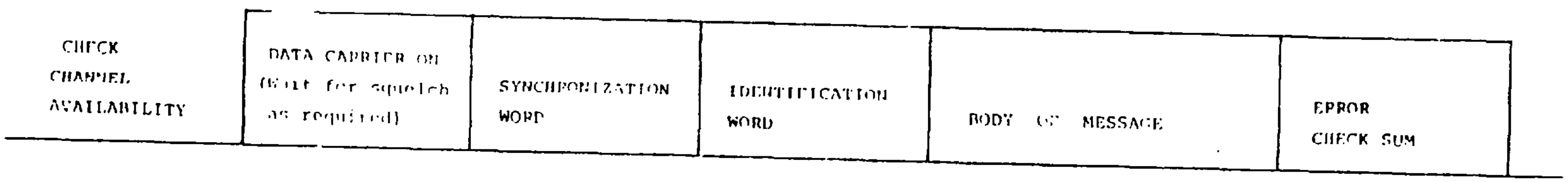

FIGURE 4-1 : PROTOTYPE MESSAGE TIME STRUCTURE

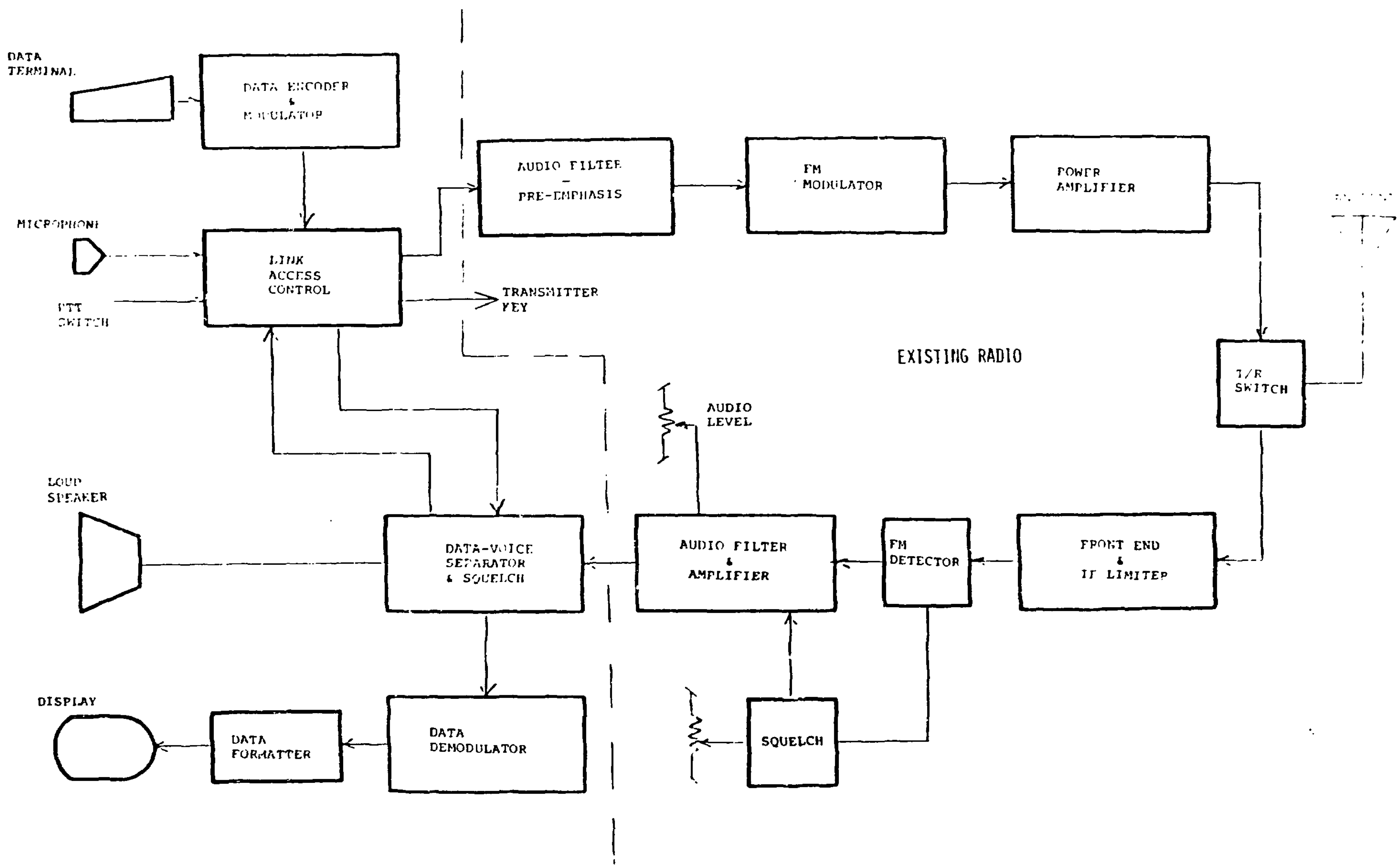

FIGURE 4-2 : BLOCK DIAGRAM OF NARROW-BAND FM (NBFM) VOICE BANDWIDTH DATA SYSTEM through an existing audio or microphone input jack. This is accomplished through the addition of link access circuitry in series with the microphone, which controls the link access, permitting either the data modem or the microphone to key the transmitter. The link access control also interfaces with the data/voice separator and squelch circuits which are located in series with the receiver audio output. This circuitry assures that the data modulator will not attempt to transmit data whil other signals are present in the channel. Received data are obtained from the audio output of the radio through circuitry which separates the voice and data tones. In the simplest case, the received data are simply tapped in parallel with the loudspeaker audio. Such an adaptation would leave the receiver squelch operating in its normal mode, causing the loudspeaker to be quieted when there was no received signal, and further, to operate when either voice or data was being received. This approach has the advantage of not requiring modifications to the existing radio, and the disadvantage of introducing a long synchronization period due to the time required to break the receiver squelch. Reference R studied the squelch time constants of typical marine FM receivers, and concluded that response times ranging from .3 to 1.2 seconds will be suffered when the squelch is operational, as shown in TABLE 4-1.

If further modifications of an existing radio are undertaken, it is possible to derive the data signal prior to the squelch, eliminating the squelch delay and further, through detection of the data carrier it is possible to squelch the loudspeaker when data are present.

A characterization of the narrow-band FM voice channel is shown in TABLE 4-2. Assuming that the channel is capable of providing acceptable voice communications, a sufficient signal-to-noise ratio exists to provide high quality data transmission.* The rate at which data may be transmitted through a voice channel is limited by the channel's 0.3-3 kc audio bandwidth and the phase amplitude of the audio channel.

*This report does not consider in detail the performance tradeoffs between various digital data modulation techniques. A review of techniques is included in references L and M

TABLE 4-1 : RECEIVER SQUELCH RESPONSE TIME
(from Reference k)

MANUFACTURER	T(SEC.)	3 T(SEC.)	COMMENTS
Carib	0.1	0.3	
Konel	0.4	1.2	Low Cost Unit
Motorola	0.135	0.4	Type used at CG Shore Stations
Bimini	0.25	0.75	Low Cost Unit
Raytheon	0.1	0.3	Time Constant is Variable - This is the specified setting.

TABLE 4-2 : NARROW-BAND FM SYSTEM PARAMETERS

1. RF BANDWIDTH AUTHORIZED FOR F2 and F4 EMISSION (reference X, §83.132 and §83.133)	20 kHz
2. FREQUENCY TOLERANCE $5 \times 10^{-6} * 1.5 * 10^8$ (reference X, §83.132f)	±750 Hz
3. CARRIER DEVIATION (100% Modulation) (reference X, §83.137b)	±5 kHz
4. INPUT BANDWIDTH	
a. LOW PASS (ref X, §83.137h)	DC - ≈3 kHz
b. EIA	300 - 3000 Hz

Both references L & M indicate that it is possible to transmit data at a rate in excess of 4800 bits/second through a nominal 3 kc voice channel. Such data rates, however, require that the channel be compensated for phase amplitude distortion and/or that multi-level modulating signals be employed. More practically, for purposes of design analysis, a data rate of 2400 bits/second is assumed. This data rate is obtainable using MSK modulation (FSK with an index of .5) employing carrier frequencies of 1200 Hz and 2400 Hz (reference K). Figure 4-3 shows the functional elements of an NBFM voice channel system. The implementation of such a system would require the following items:

- Possible modification of the existing VHF radio. This is required if elimination of the squelch delay is desired. Notice that there are two possible variations here
  - (1) If the assigned channel is used only for data, then it is possible to externally disable the speaker when the data channel is selected.
  - (2) It is possible to modify only the VTS center receiver to eliminate the squelch delay, providing increased message speed from the vessel to the VTS center, while providing for slower but lower cost data transmission from the VTS to the vessel.
- A data modem/link controller to provide the digital communication capability. This component provides data for display on a user selected device, it accepts pre-programmed user identification data, manually entered current user status data from a data input terminal and optional Loran-C time difference data.
- The data input/output console which can range from a very simple pre-programmed identification message and alarm light to a complex map display of all vessels for which position data has been received.

The costs associated with each of the system elements are shown in TABLE 4-3. These are based on conversations with receiver/modem manufacturers. The cost of modifying the existing radio is highly variable and reflects more the time required for a technician to gain access to the radio than the actual cost of

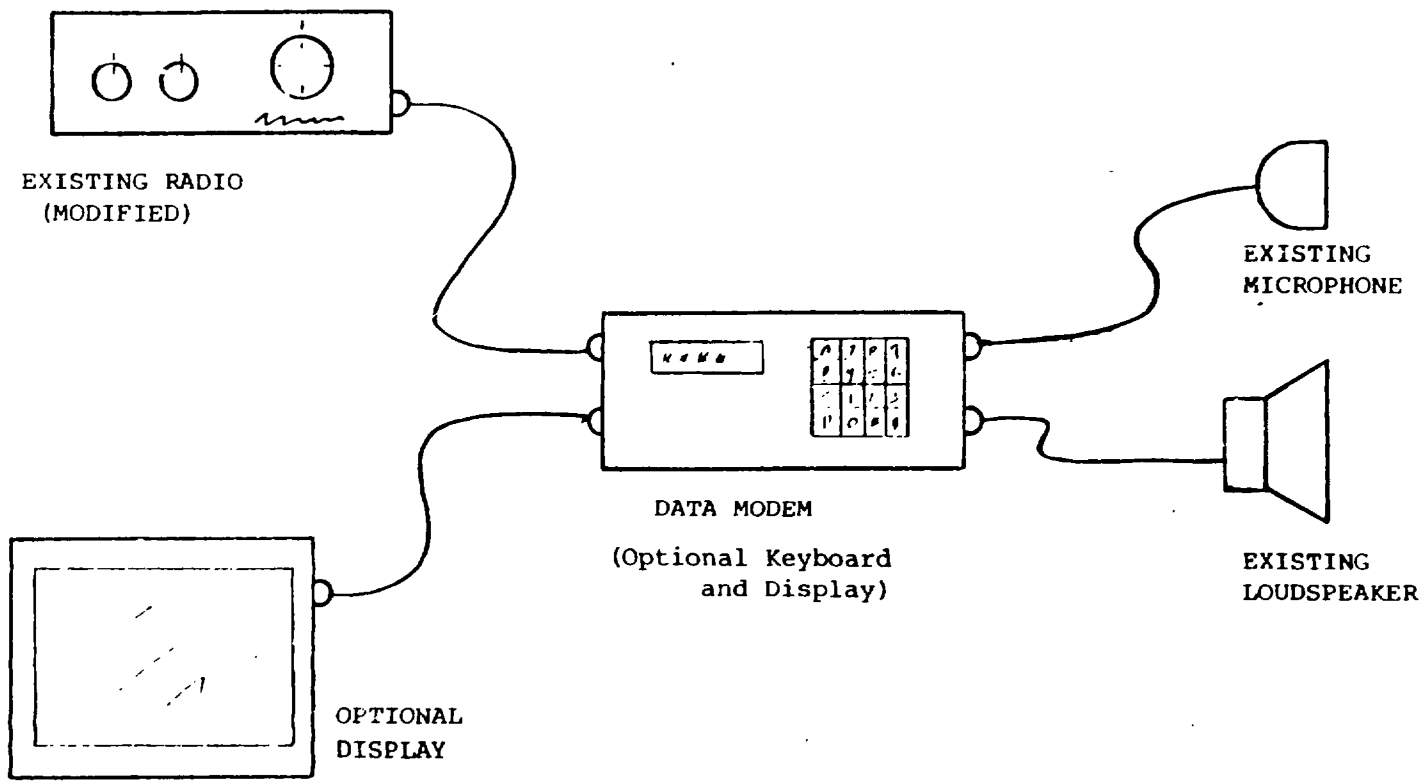

FIGURE 4-3 : NBFM VOICE CHANNEL SYSTEM ELEMENTS

TABLE 4-3 : COSTS FOR VOICE BANDWIDTH SYSTEM, NBFM

ELEMENT	ESTIMATED COST
Modification of existing radio (see text)	$300
Modem	$300
Optional Modem Keyboard/Display	$250
Optional External Display	$not quoted

installing the required hardware. The required modification could be provided in new receivers at little or no cost. The modem costs are based on the current selling price for a similar modem available to the land radio mobile community. The input/output display is not estimated, as that estimate will reflect a wide variation in cost as a function of desired capability.

4.2 Wide-Band Modulation of Narrow-Band FM

The second system approach considered is wide-band or direct modulation of a narrow-band FM transmitter and the detection of tones derived directly from the discriminator. This permits the transmission of higher data rates, as the frequencies are not restricted by a 3 kc voice filter. The system parameters assumed for such a wide-band system are shown in TABLE 4-4. There is presently no authorized operation of this type in the maritime band, therefore it is necessary to introduce constraints assuming that modulation techniques which did not interfere with adjacent FM channels would be acceptable. A block diagram for the wide-band direct modulation system is shown in Figure 4-4. This system does not preclude the use of voice over the data channel, but does require a more extensive modification of the existing FM radio. This is not seen as a severe disadvantage, however, as it is felt that the major cost in modifying an existing radio is connected with the logistics of performing the modification rather than the cost of the modification itself. A data rate of 16k bits/second is assumed for the direct wide-band modulation technique. This data rate reflects actual data rates achieved over similar channels (ref.L) or scaled from rates obtained in similar systems (ref.I). A suitable modulation would be phase continuous FSK (MSK) signal, generated either through Manchester (di-phase) coding or other techniques. A system similar to this is described in reference G (a cellular mobile telephone system) and reference I (a high capacity microwave system). Phase continuous modulation is suggested, as it exhibits minimal amplitude variation and a very well controlled and narrow band spectrum. A block diagram showing the essential elements of a wide-band data modulation system integrated with an existing FM radio is shown in Figure 4-5.

TABLE 4-4 : WIDE-BAND NBFM SYSTEM PARAMETERS

1.	RF BANDWIDTH (F4, also assumed for F9 and P9) (reference X, §83.134c provides for authorized exceptions)	20 kHz
2.	FREQUENCY TOLERANCE	±750 Hz
3.	CARRIER DEVIATION	No constraint assumed
4.	INPUT BANDWIDTH	No constraint assumed

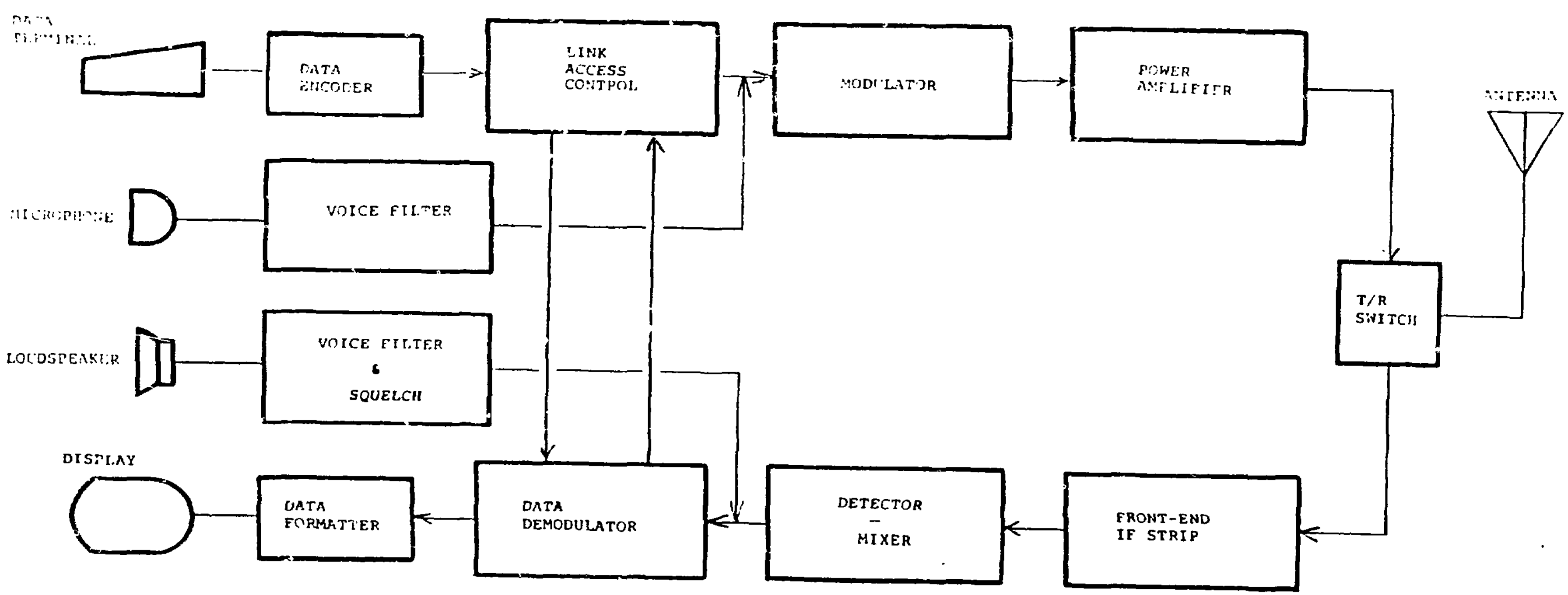

FIGURE 4-4 : BLOCK DIAGRAM OF WIDE-BANDWIDTH, NBFM DIRECT MODULATION SYSTEM

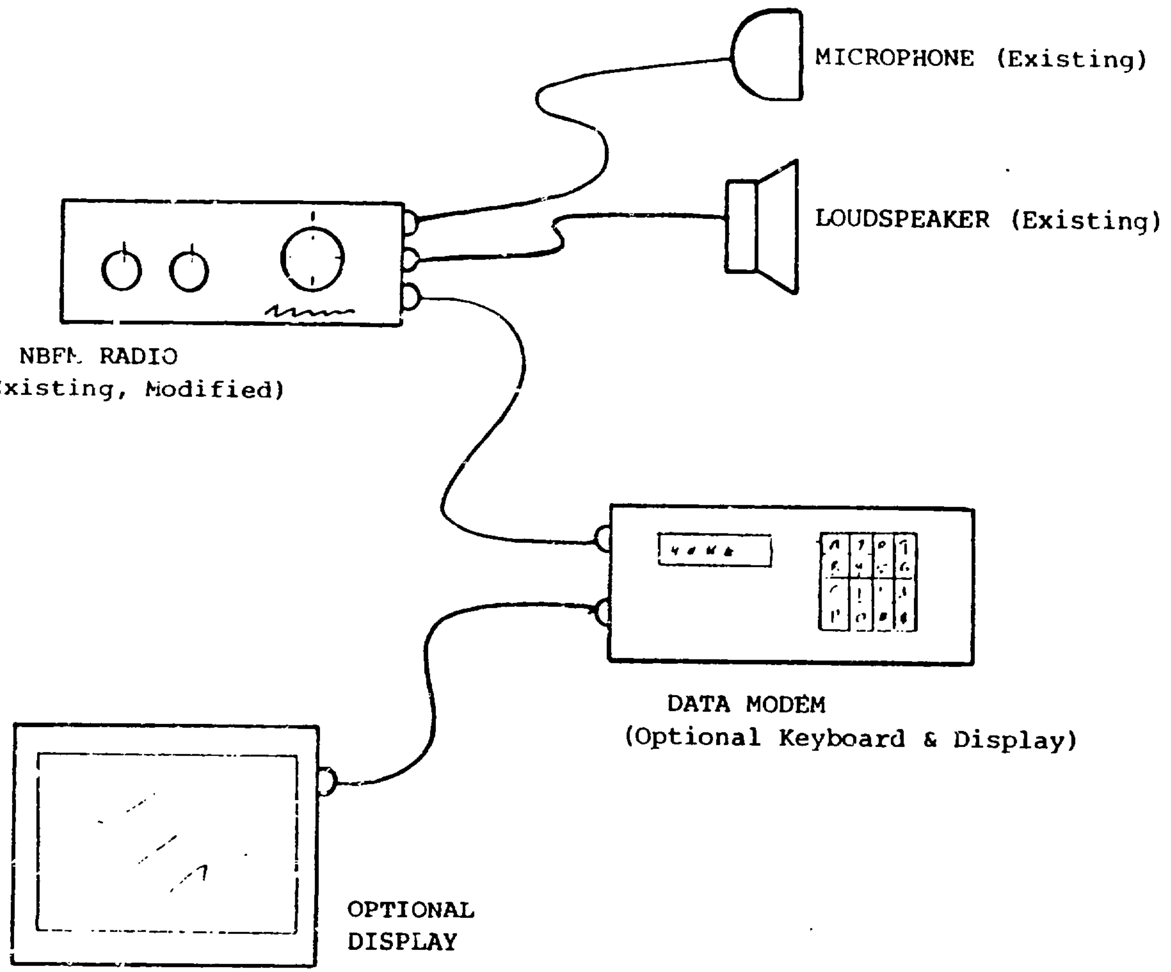

FIGURE 4-5 : WIDE-BAND, NBFM DIRECT MODULATION SYSTEM ELEMENTS

TABLE 4-5 : WIDE-BAND NBFM SYSTEM COSTS

ELEMENT	ESTIMATED COST
MODIFICATION OF EXISTING RADIO (see text)	$350
MODEM	$450
OPTIONAL MODEM KEYBOARD & DISPLAY	$250
OPTIONAL EXTERNAL DISPLAY	$not quoted

The costs associated with these elements are shown in TABLE 4-5. When compared with voice channel modulation, the cost of the existing receiver modification would be slightly higher due to the necessity of interfacing in a part of the radio which is not as accessable as the audio circuit, and an increase in the cost of the modem due to the higher speed circuitry involved. Once again, the data input and display portions are not quoted.

4.3 Non-NBFM Modulation of a VHF Channel

The third approach considers the direct modulation of the VHF channel and generally would not employ the existing VHF FM radio. A generalized block diagram for this class of system is shown in Figure 4-6. Three variations of this technique were considered:

1. Direct modulation of data into the existing channel; employing for example, Manchester coding
2. Frequency-hopped FSK to provide a random access, multi-user system
3. Inter-channel single sideband transmission.

The direct modulation of data into the existing VHF FM spectrum should provide a data rate of approximately 32k-40k bits/second, thus providing a data rate approximately twice that obtainable through the wide-band modulation of an FM transceiver. Direct modulation is not considered in detail in this report. While the technique does offer the highest data rate, that rate in light of the performance of the 16k bit/second wide-band technique, is far in excess of projected demands. If selected, this technique would require either extensive modification of the existing NBFM transceiver, or a separate data transceiver, and would use less than 10% of the channel capacity (at 300 advisories/hour and 30 vessel reports per advisory). The question of the compatibility of NBFM voice and directly modulated data on the same channel is beyond the scope of this study.

A frequency-hopped FSK (FH-FSK) system uses pseudorandom frequency modulation of each user's transmitter to permit many carriers to transmit simultaneously in the same channel, without significant interference. This technique permits many users to randomly access the same communication channel independent of each other with only a degradation of signal quality resulting as the numbers of users approaches the system's capacity. This technique is presently being considered for cellular mobile radio telephone systems (ref T). The system proposed in (ref T) would provide each user with a 32k bit/second channel by spreading each signal over the entire 20 MHz mobile radio telephone channel. Under these operating conditions, the system can accomodate on the order of 100-200 simultaneous users. This technique was rejected for the following reasons:

- For the system to work properly, it is necessary that the received signal from each user be nearly equal in intensity. In the referenced mobile radio system, the power of the transmitters is adjusted by the base station to provide this condition. Such power adjustments and equalization in a signal strength is relatively easy in the small cells assigned in mobile telephone systems, but difficult over the area covered by a single VTS.
- When the 20 MHz bandwidth allocated for the mobile radio system is scaled to 20 kHz available in a single VHF channel, the data rate is reduced to approximately 32 bits/second, which was felt to be unacceptable slow.
- Following the reasoning used for the direct modulation technique, again less than 10% of the channel capacity would be used.
- Simultaneous voice transmission would be difficult or impossible.

The use of a single sideband channel placed between two existing 25 kHz FM channels is a technique which offers the advantages of a data-only channel providing reasonable data rates with a minimal, if not negligible, effect on the existing FM voice traffic. The use of amplitude compandored, single sideband (ACSSB) has been explored as a way of expanding the number of channels available in the VHF and UHF mobile radio bands. This work is summarized in reference V. Because single sideband modulation directly translates voice and data channels up to the VHF band, a 5 kc voice channel only occupies a 5 kHz spectrum in the VHF band. Using this technique, it is possible to fit as many as five, 5 kc channels in the 25 kHz slot presently occupied by a single narrow-band FM channel.

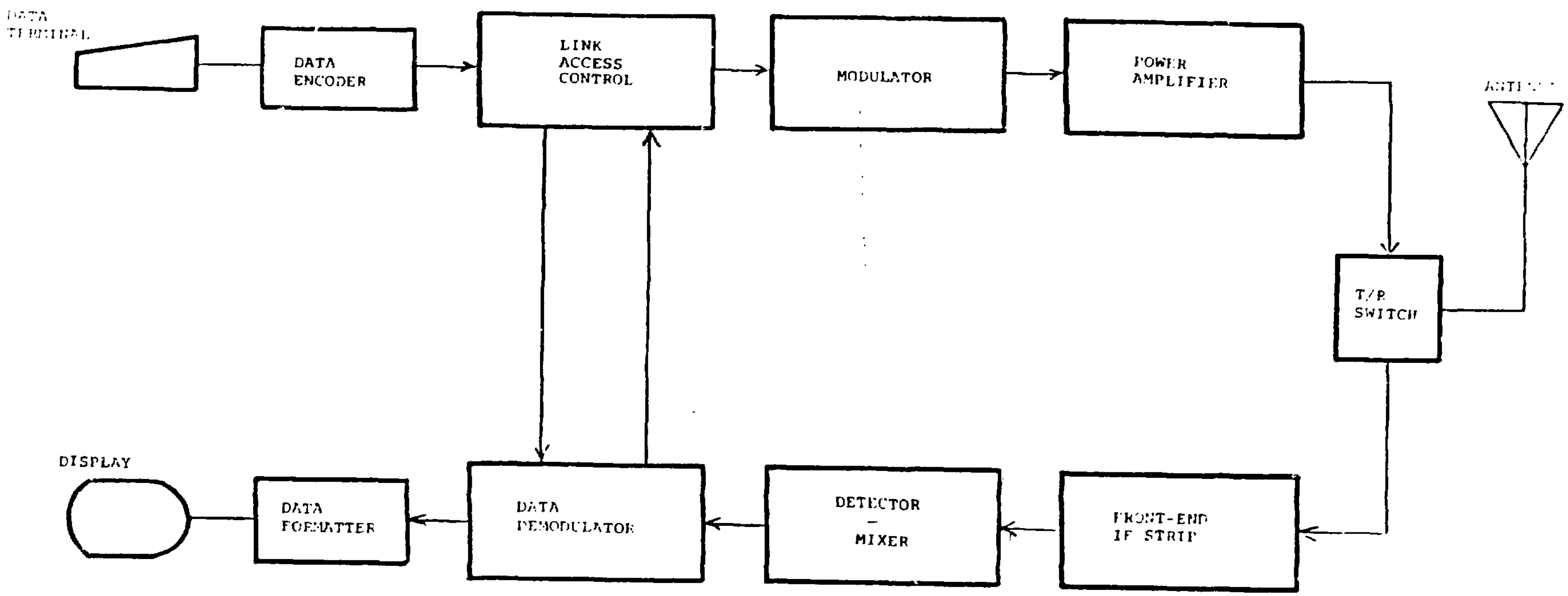

FIGURE 4-6 : BLOCK DIAGRAM OF NON-NBFM DATA SYSTEM

Two figures of significance from reference V are reproduced as Figures 4-7 and 4-8. Figure 4-7 shows the relative spacing and spectrum occupation of NBFM channels with respect to single sideband channels. These channels are labeled as mid, edge and near channels to describe their relationship to the presently existing 25 kHz narrow-band FM channel. Figure 4-8 shows the effect of ACSSB on an adjacent FM channel. Specifically, this figure shows that an ACSSB channel placed between two narrow-band FM channels should cause less interference than two adjacent narrow-band FM signals.

Three technical problems which had to be considered prior to using single sideband for voice in the VHF band do not exist when data are transmitted. These are:

- -The control of both the clipping level and the level of the pilot tone sent along with the voice signal to prevent undue spectrum spreading by the non-linear final single sideband amplifier
- -The need to amplitude compress the signal to obtain an acceptable signal quality on 'weak' syllables
- -The need to transmit a pilot tone to provide automatic gain control in the face of variable audio amplitude and to provide frequency correction to eliminate the 'Donald Duck' effect from the received single sideband signals.

These problems are minimized or disappear if continuous phase data are transmitted. The transmission of continuous phase data (e.g. MSK) minimizes the spreading due to non-linearity of the final amplifier. Further, as only the frequency information is of concern, the received data are amplified to limiting, eliminating the need for automatic gain control, which, along with the ability to extract the reference carrier from the data, eliminates the need for a pilot tone.

The data rate of a single sideband channel is constrained by the final VHF signal bandwidth. If a single sideband technique is selected, the bandwidth and spacing of the proposed channels should be aligned with the proposed specifications for ACSSB for voice so that future expansions from narrow-band FM to ACSSB may be accomplished with a minimum conflict. Assuming the

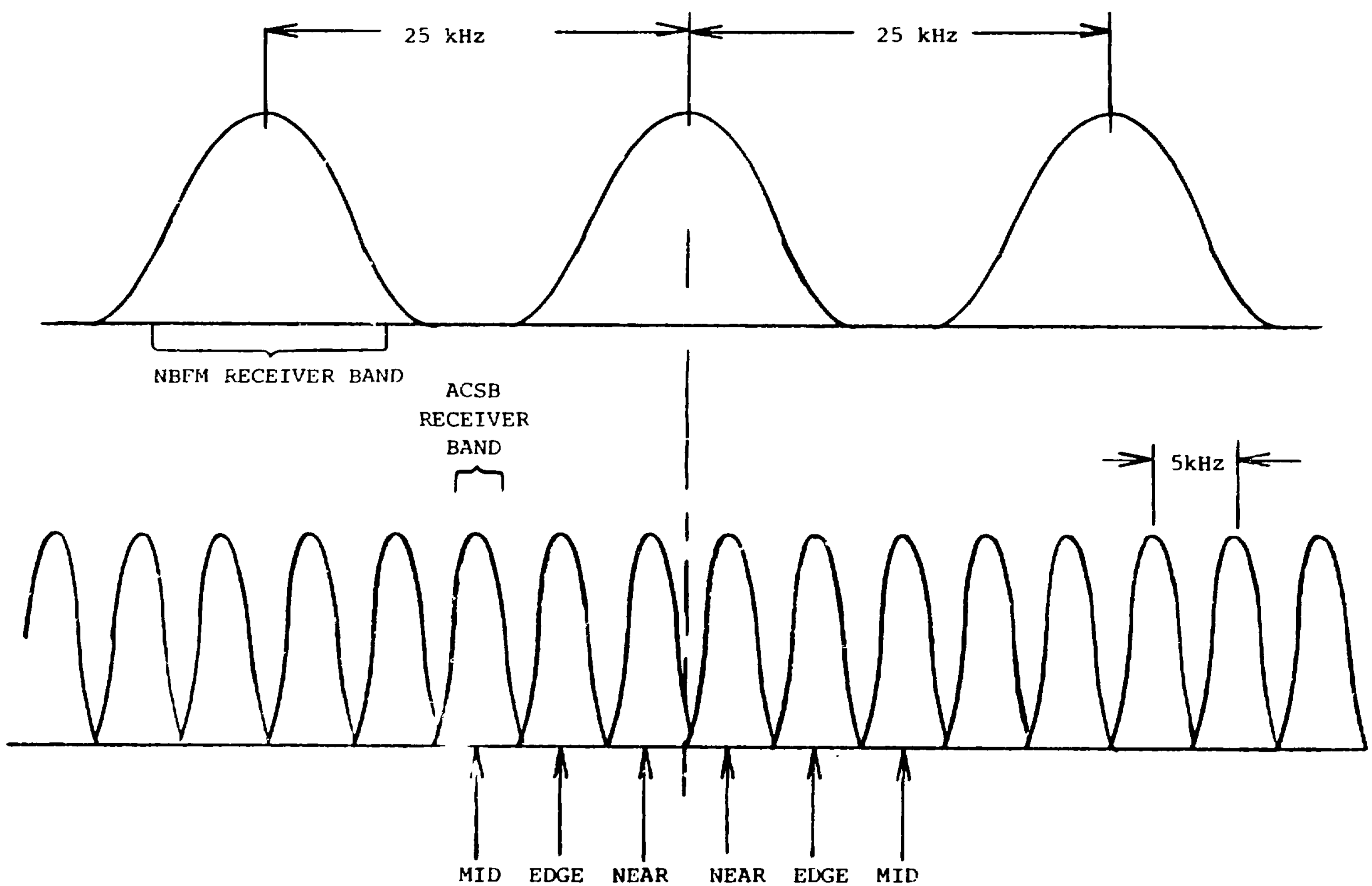

FIGURE 4-7 : RELATIVE SPACING OF NBFM and ACSB CHANNELS

(After Figure 5, reference V)

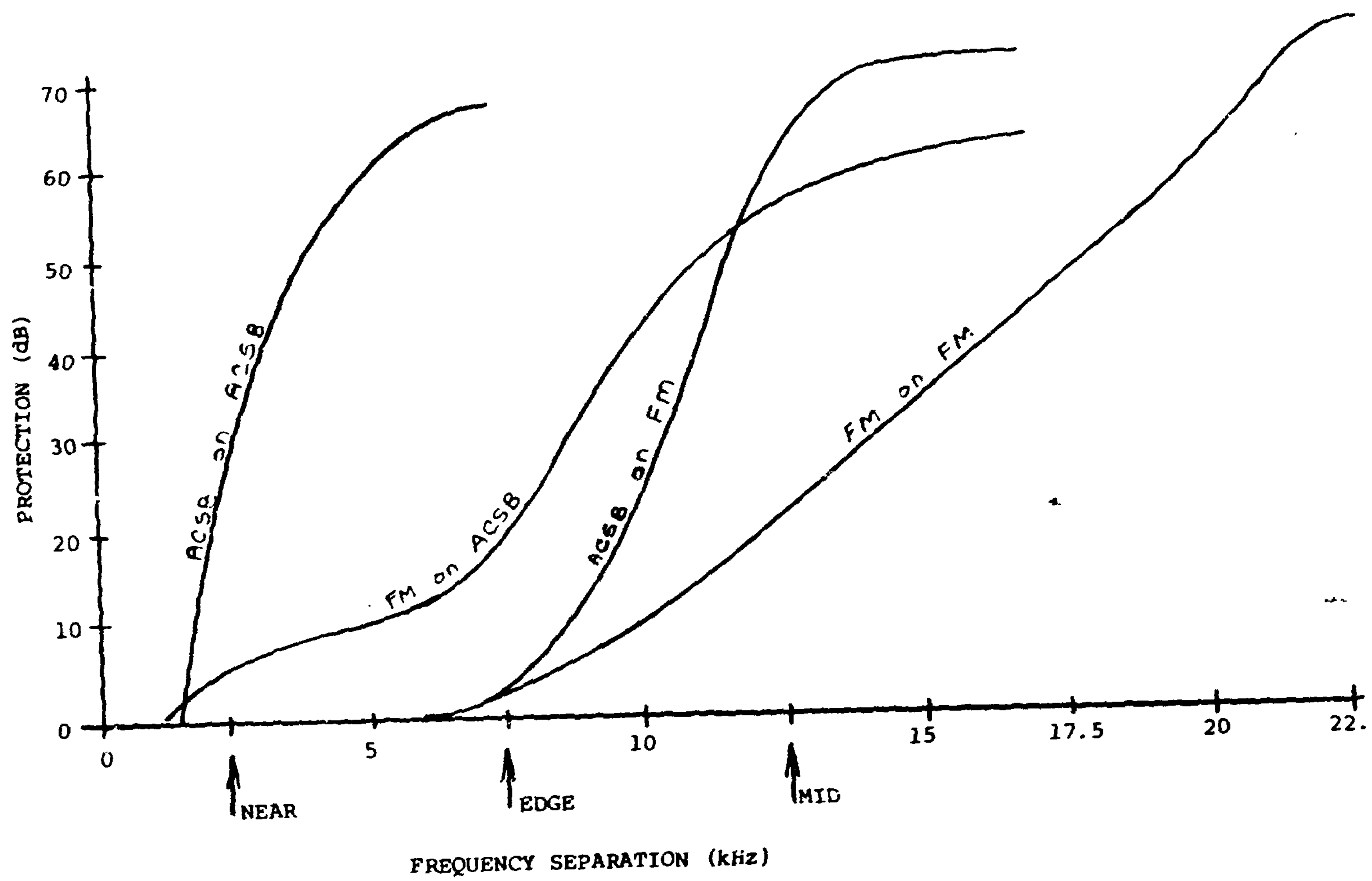

FIGURE 4-8 : PROTECTION RATIO vs FREQUENCY SEPARATION FOR NBFM & ACSB RADIOS
(After Figure 6, reference V)

use of a single, SSB voice channel and noting that the phase linearity and filters provided for this channel may be specified at the time of manufacture for data transmission, a data rate of 4800 bits/second appears reasonable (references L and M).

A block diagram for a single sideband data-only system is shown in Figure 4-9. The estimated cost for this system (TABLE 4-6) is estimated as being equal to the cost of a high quality narrowband FM radio with a modem. This is based on the assumptions presented in reference V, that the cost of ACSSB voice equipment will be compatible with the costs of existing narrow-band FM equipment.

If ACSSB replaces NBFM for voice, and assuming that an auxiliary data connector is provided, only the appropriate modem will be required.

TABLE 4-6. SSB DATA SYSTEM COSTS

ELEMENT	ESTIMATED COST
SSB Transmitter & Receiver	$1,500 - $3,000
MODEM	$300
Optional Modem Keyboard and Display	$250
Optional External Display	$not quoted

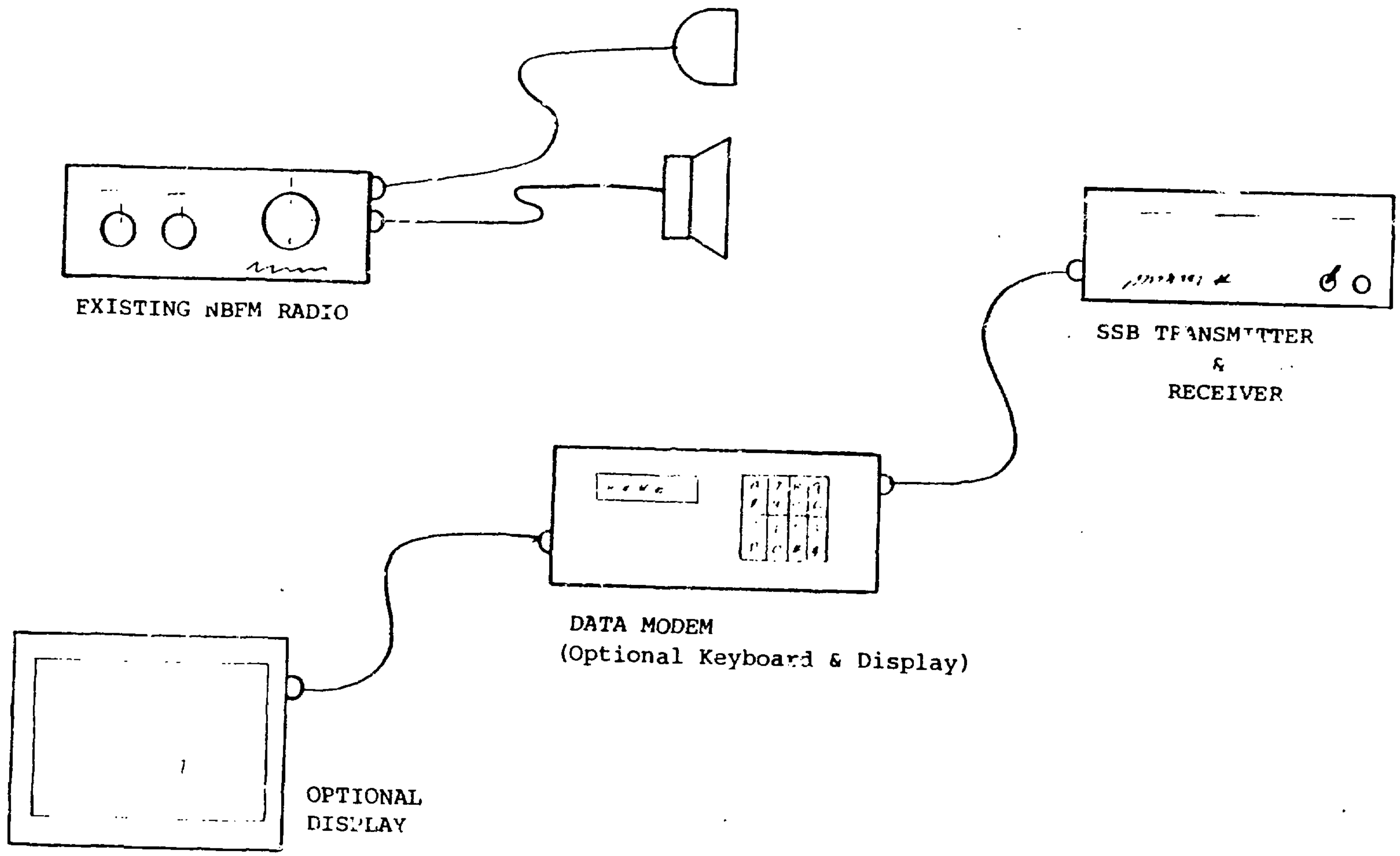

FIGURE 4-9 : SSB DATA SYSTEM ELEMENTS

5. ANALYSIS OF CAPACITY

The capacities of the three VTS data systems described in section 4 are analyzed in this section. This analysis is based on:

-Channel usage statistics presented in section 2.

-Messages proposed in section 3.

-Data rates stated in section 4.

For each system, the time necessary to transmit a message of n bits is shown in TABLE 5-1. The main difference between the two first entries is the assumption concerning the system squelch. If the squelch is used, approximately 1.2 seconds must be added to each data transmission to allow for the squelch break time. The random delay shown allows for the introduction of a random wait time between the detection of a clear channel and the start of the transmission. This time helps break up races for the channel when several users are cued up waiting to transmit data. Modem synchronization time allows for several cycles of the data carrier to provide synchronization between the data transmitting clock and the receiver clock. The message duration is directly proportional to the number of bits transmitted and the reciprocal of the assumed data rate. The data rates for each channel type are listed in terms of characters/second, assuming 10 bits per character. Using the formulas of TABLE 5-1, the time necessary to transmit each of the data messages described in TABLES 3-7a through 3-7e are listed in TABLE 5-2.

The most frequently sent message and the one with most variability in the time required to send it is the VTS-to-vessel advisory update. The length of this message is proportional to the number of vessel advisories being issued. The time required to send advisories including 1, 3, 10 and 30 vessels are listed. The actual number of vessel advisories required (or desired) is an operational consideration and is not addressed in this report. When data message lengths are in excess of approximately 1-2 seconds, it may be difficult to send the data as one single message in a channel which also includes voice (see section 3). In these cases, it will be necessary to issue several shorter advisory messages in lieu of a single lengthy message.

TABLE 5-1. MESSAGE TRANSMISSION TIME FOR N CHARACTERS AS A FUNCTION OF DATA TRANSMISSION CHANNEL TYPE

CHANNEL TYPE	BAUD RATE (Characters/Sec, 10 Bits/Char.)	RANDOM DELAY (0-4msec)	SQUELCH/ LINK ACCESS	MODEM SYNC	MESSAGE ($*10^{-3}$sec)	TOTAL MESSAGE TIME ($*10^{-3}$sec)
NBFM Voice + Data (System Squelch in use)	240	.002	1.2sec	.005	N*4.17	1200+7+N*4.17
NBFM Data Only (No Squelch)	240	.002	0	.005	N*4.17	7+N*4.17
NBFM Wide-band Data	1600	.002	0	.005	N*.625	7+N*0.625
SSB Direct Mid-Channel	480	.002	0	.005	N*2.083	7+N*2.083

TABLE 5-2. DURATION OF MESSAGE ELEMENT (SECONDS) vs MESSAGE TYPE AND DATA TRANSMISSION CHANNEL TYPE

	CHARACTERS IN MESSAGE (Table 3-7)	Duration of Message Element (seconds) NBFM Data + Voice (Noise Squelch)	NBFM Data Only	WIDE-BAND Data	SSB
Vessel-to-VTS Initial Contact	150	1.836	0.633	0.101	0.319
VTS-to-Vessel Acknowledgement	46	1.402	0.199	0.036	0.103
VTS-to-Vessel Position Request	46	1.402	0.199	0.036	0.103
Vessel-to-VTS Position Update	90	1.585	0.382	0.063	0.194
VTS-to-Vessel Situation Update	18	1.285	0.082	0.018	0.044
PLUS : 1 Vessel	73	0.304	0.304	0.046	0.152
3 Vessels	219	0.913	0.913	0.137	0.456
10 Vessels	730	3.044	3.044	0.456	1.521
30 Vessels	2190	9.132	9.132	1.369	4.562
Vessel-to-VTS System Departure Message	44	1.393	0.190	0.035	0.099
VTS-to-Vessel Departure Acknowledgement	46	1.402	0.199	0.036	0.103

Examination of the time required to send messages other than advisory messages and the proportion of time non-advisory messages are sent (TABLE 3-4) permits the data capacity to be summarized graphically by considering only the number of advisory messages per hour. For example, to send an advisory concerning a single vessel to 296 ships (TABLE 3-5) a total time of approximately 1370 seconds per hour is required (22.83 minutes). If the projected 13 check-in and 9.6 check-out messages are added, only an additional 14.55 seconds of channel time is required per hour.

The results for the four systems in TABLE 5-2 are shown in Figures 5-1, 5-2, 5-3 and 5-4. The worst case channel loading for each case occurs when 30-vessel advisories are issued per follow-up request, and in this case the severest loading occurs for the NBFM voice system with the squelch operational. For the worst case NBFM channel, saturation occurs with approximately 270 users. The least effect on channel capacity is obtained for the wide-band FM mode with 16k bits/second data transmission. In this case, the maximum anticipated growth to 296 advisories per hour will require approximately 15% of the capacity of an existing voice channel. Further, the brief data message obtained at the higher data rate will cause fewer messages to be destroyed by the initialization of a voice transmission during the message, permitting the high effective throughput to be maintained even with dual voice/data usage of the channel.

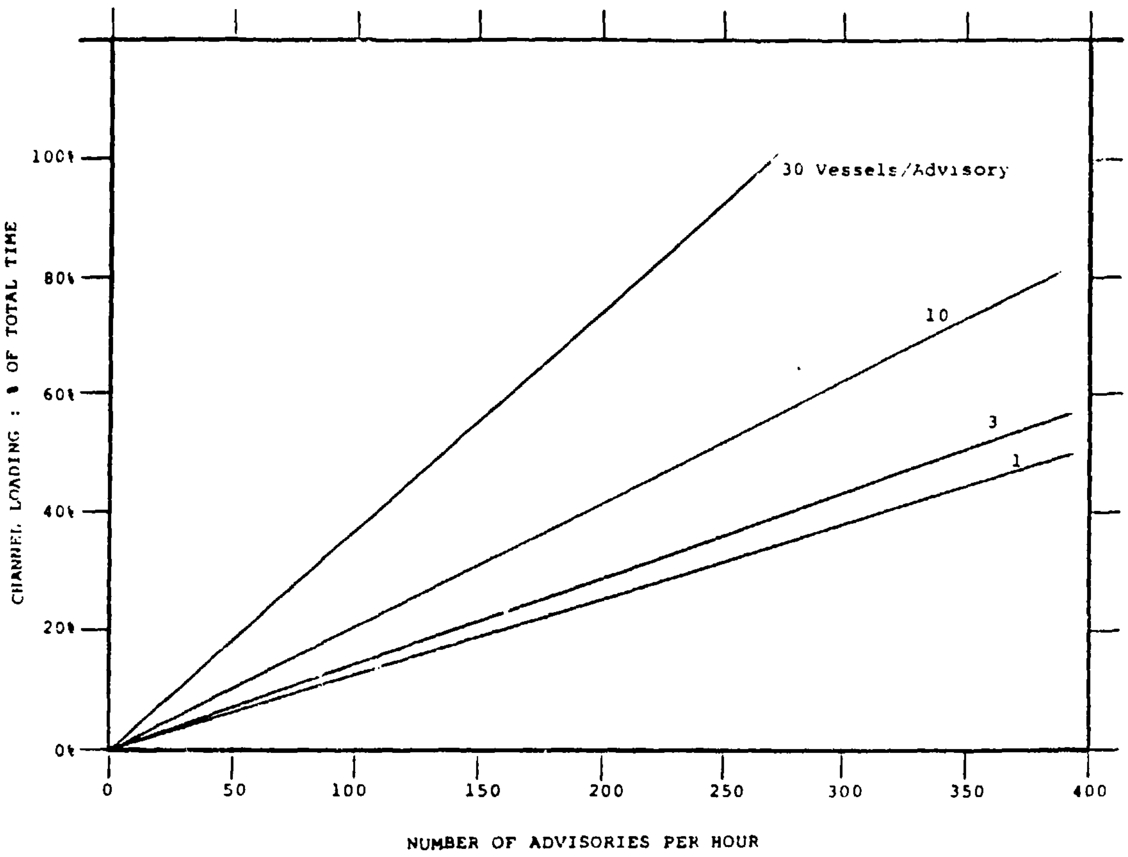

FIGURE 5-1 : NBFM, 2400 B/S DATA WITH SQUELCH
CHANNEL LOADING vs ADVISORIES ISSUED PER HOUR
FOR 1, 3, 10 and 30 VESSELS PER REPORT

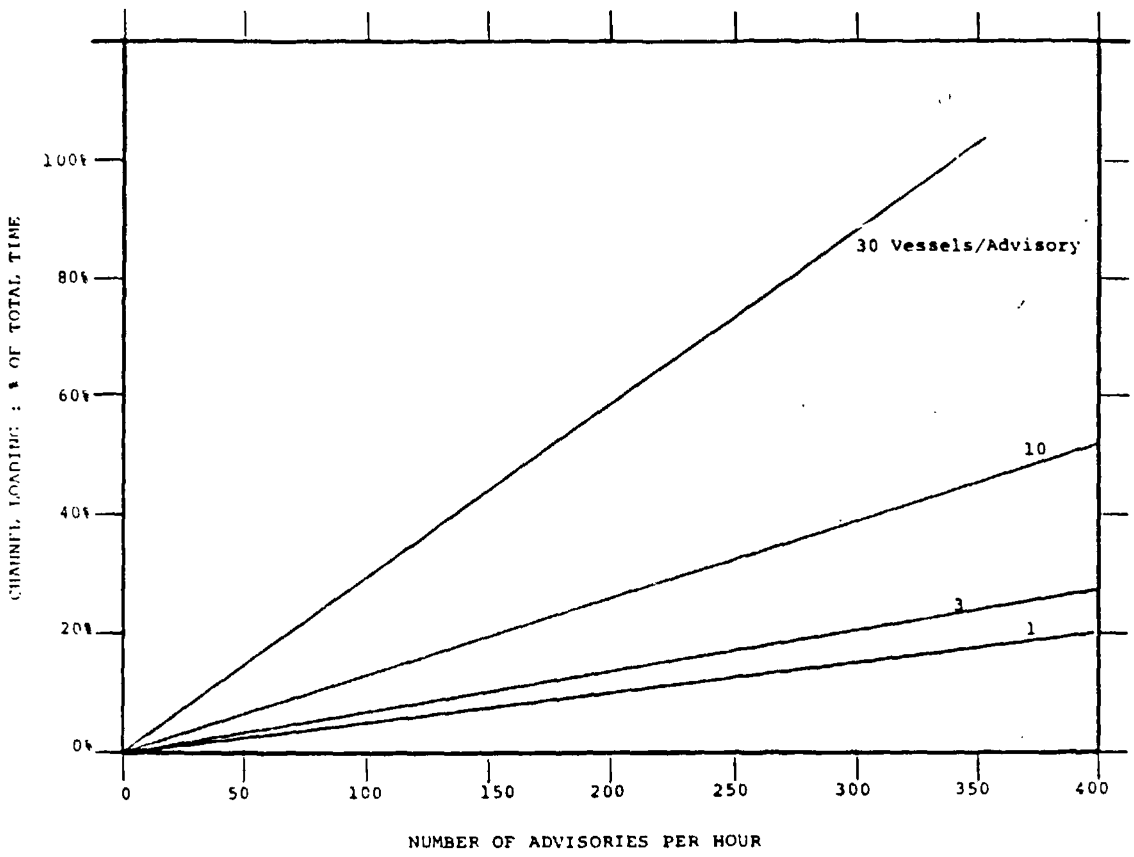

FIGURE 5-2 : NARROW-BAND FM, 2400 B/S, NO SQUELCH
CHANNEL LOADING vs ADVISORIES ISSUED PER HOUR
FOR 1, 3, 10 and 30 VESSELS PER REPORT

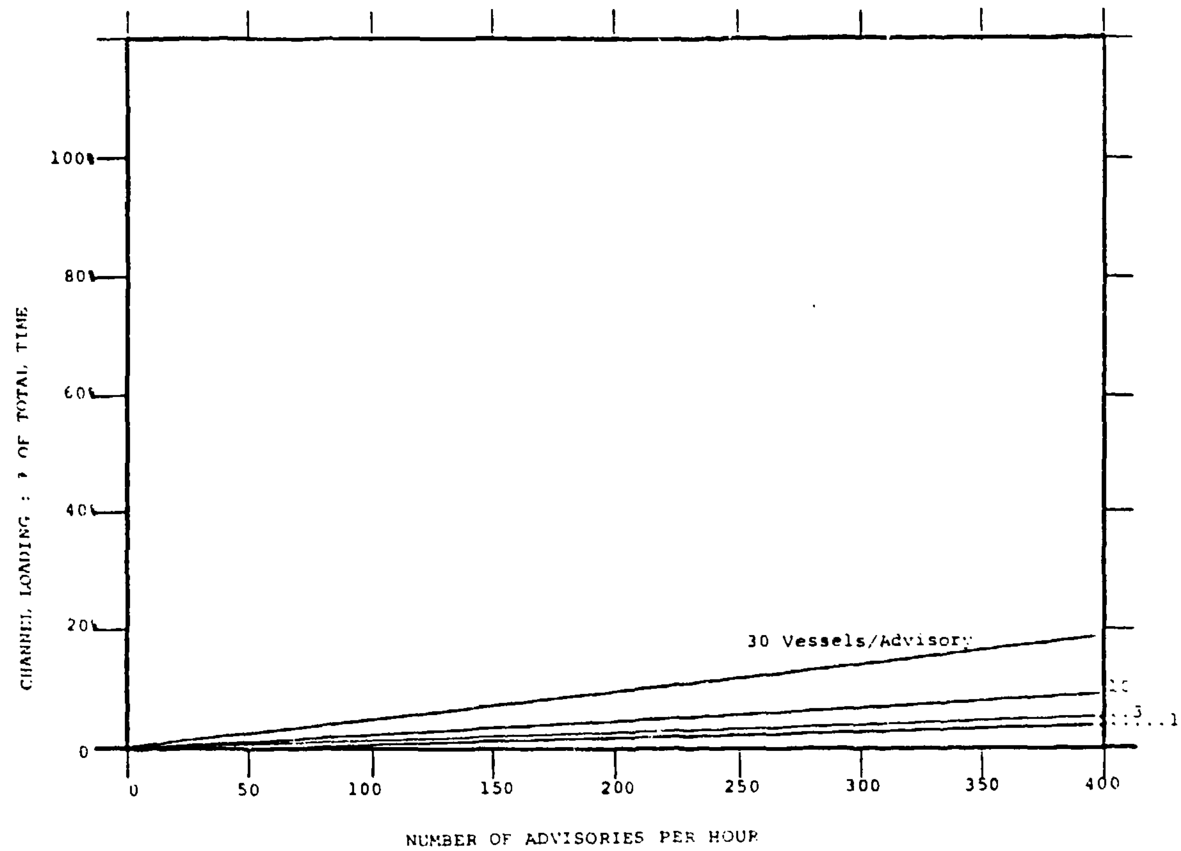

FIGURE 5-3 : WIDE-BAND NBFM, 16k B/S,
CHANNEL LOADING vs ADVISORIES ISSUED PER HOUR
FOR 1, 3, 10 and 30 VESSELS PER REPORT

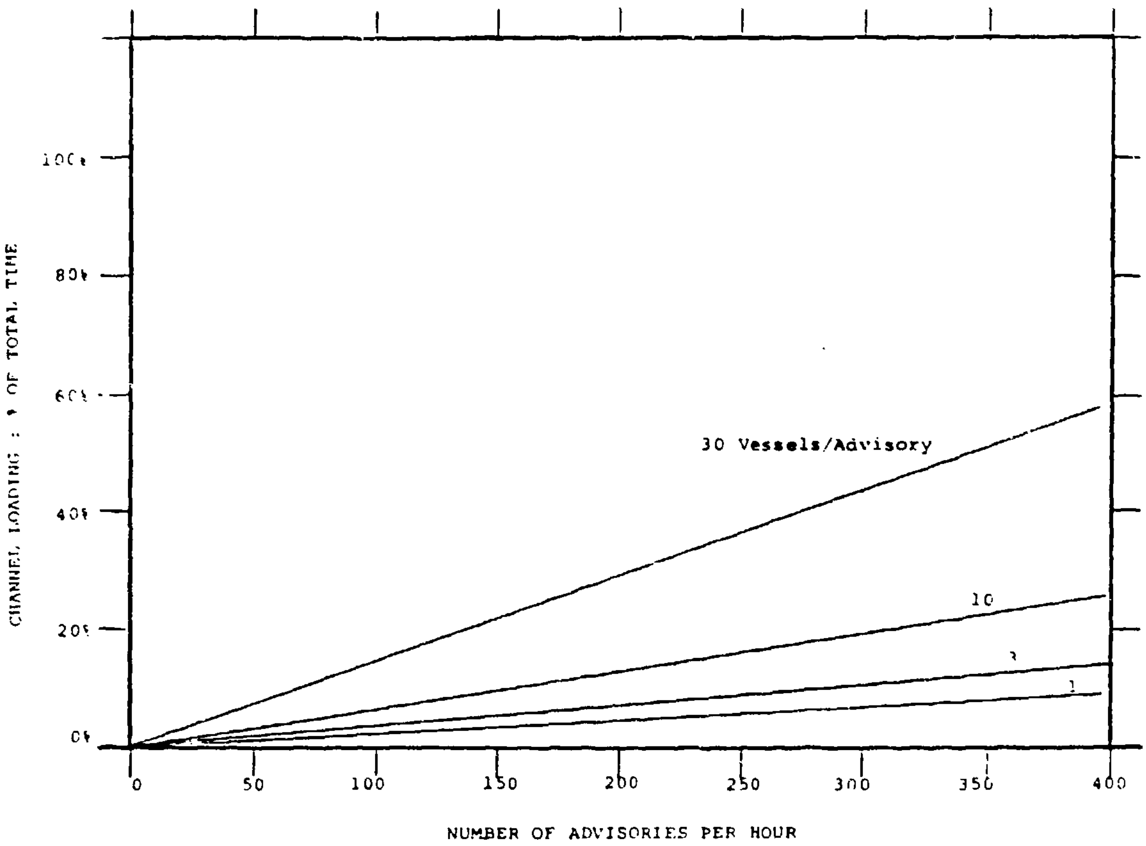

FIGURE 5-4 : MID-BAND SSB, 4800 B/S,
CHANNEL LOADING vs ADVISORIES ISSUED PER HOUR
FOR 1, 3, 10 and 30 VESSELS PER REPORT

6. SUMMARY

Based on the data presented in this report, the following conclusions are stated:

(1) An NBFM voice plus data system which retains the use of the standard receiver squelch should be rejected in favor of adding a data-operated squelch. While this requires further modification of the existing radio, the differential cost is small for the data capacity gained.

(2) The length of the data messages can be reduced by approximately 40% if a modified ASCII code is employed. In doing this or in considering a more compact, specialized code, the advantages of maintaining a standard communication interface should be borne in mind (e.g. international use).

(3) The use of single sideband modulation is to be preferred if a data-only channel is desired, as this technology holds the promise of adding the required data channel without requiring any additional spectrum.

(4) When considered from the point of view of the overall balance between equipment costs, spectrum usage and channel effeciency, the wide-band modulation of digital data on an existing NBFM transmitter appears to be optimal.

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APPENDIX - REPORT OF NEW TECHNOLOGY

The work performed under this contract, while leading to no new invention, has determined communication channels and modulation techniques available for future expansion of vessel position monitoring. Frequency allocations, applicable modulation techniques and the impact of change from voice only to voice/data and data-only communications were considered in determining alternative technological approaches to future system requirements.